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Compilation of 1988 Annual Reports  
of the Navy ELF Communications System  
Ecological Monitoring Program

Volume 3 of 3 Volumes:  
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<p>This is the seventh compilation of annual reports for the Navy's ELF Communications System Ecological Monitoring Program. The reports document the progress of eight studies performed during 1988 at the Wisconsin and Michigan Transmitting Facilities. The purpose of the monitoring is to determine whether electromagnetic fields produced by the ELF Communications System will affect resident biota or their ecological relationships.</p> <p>See reverse for report titles and authors.</p>					
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## 19. Abstract (Continued)

## G. Bird Species and Communities

University of Minnesota-Duluth

Blake, J. G.; Hanowski, J. M.; Niemi, G. J.

## H. Aquatic Ecosystems

Michigan State University

Burton, T. M.; Eggert, S.; Marod, S.; Molloy, J.; Mullen, D.;

Stout, R. J.; Taylor, W. W.

## FOREWORD

The U.S. Navy is conducting a long-term program to monitor for possible effects from the operation of its Extremely Low Frequency (ELF) Communications System to resident biota and their ecological relationships. The program is being implemented by IIT Research Institute (IITRI) under contract to the Space and Naval Warfare Systems Command (SPAWAR). IITRI provides engineering support and coordinates the efforts of investigators. Monitoring projects are being carried out through subcontract arrangements between IITRI and study teams at several universities.

This is the seventh compilation of annual reports prepared by university study teams. Each report chronicles the data collection and data analysis activities for a monitoring project during 1988. As in the past, each report has been reviewed by four or more scientific peers. Investigators have considered and addressed peer critiques prior to providing their reports for the compilation, and each report has been printed without further change or editing by either SPAWAR or IITRI.

During 1987, data collection was concluded for studies of wetland biota and slime molds, with the overall findings of each study to be documented during the following year. Documentation of the results for these two projects, previously presented as part of the compilation of annual reports, will be made available as separate reports.

Reports other than this compilation chronicle electromagnetic exposures at study sites or summarize the overall technical progress of the program. A listing of all reports prepared since the inception of the program in 1982 appears immediately following the index of 1988 annual reports. All reports have been provided to the National Technical Information Service for unlimited distribution.

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ECOLOGICAL MONITORING PROGRAM

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1. Compilation of 1987 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program. IIT Research Institute, Technical Report E06595-2, 1988. Vol. 1, 706 pp.; Vol. 2, 385 pp.; Vol. 3, 491 pp.
2. Compilation of 1986 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program. IIT Research Institute, Technical Report E06549-38, 1987. Vol. 1, 445 pp.; Vol. 2, 343 pp.; Vol. 3, 418 pp.
3. Compilation of 1985 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program. IIT Research Institute, Technical Report E06549-26, 1986. Vol. 1, 472 pp.; Vol. 2, 402 pp.; Vol. 3, 410 pp.
4. Compilation of 1984 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program. IIT Research Institute, Technical Report E06549-17, 1985. Vol. 1, 528 pp.; Vol. 2, 578 pp.
5. Compilation of 1983 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program. IIT Research Institute, Technical Report E06549-8, 1984. Vol. 1, 540 pp.; Vol. 2, 567 pp.
6. Compilation of 1982 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program. IIT Research Institute, Technical Report E06516-5, 1983, 402 pp.

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7. Haradem, D. P.; Gauger, J. R.; Zapotosky, J. E. ELF Communications System Ecological Monitoring Program: Electromagnetic Field Measurements and Engineering Support--1988. IIT Research Institute, Technical Report E06595-5, 1989, 69 pp. plus appendixes.
8. Haradem, D. P.; Gauger, J. R.; Zapotosky, J. E. ELF Communications System Ecological Monitoring Program: Electromagnetic Field Measurements and Engineering Support--1987. IIT Research Institute, Technical Report E06595-1, 1988, 54 pp. plus appendixes.
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#### Program Summaries

13. Zapotosky, J. E. Extremely Low Frequency (ELF) Communications System Ecological Monitoring Program: Summary of 1987 Progress. IIT Research Institute, Technical Report E06595-3, 1989, 64 pp. plus appendixes.
14. Zapotosky, J. E. Extremely Low Frequency (ELF) Communications System Ecological Monitoring Program: Summary of 1986 Progress. IIT Research Institute, Technical Report E06549-39, 1987, 63 pp. plus appendixes.
15. Zapotosky, J. E. Extremely Low Frequency (ELF) Communications System Ecological Monitoring Program: Summary of 1985 Progress. IIT Research Institute, Technical Report E06549-27, 1986, 54 pp. plus appendixes.
16. Zapotosky, J. E. Extremely Low Frequency (ELF) Communications System Ecological Monitoring Program: Summary of 1984 Progress. IIT Research Institute, Technical Report E06549-18, 1985, 54 pp. plus appendixes.
17. Zapotosky, J. E.; Abromavage, M. M.; Enk, J. O. Extremely Low Frequency (ELF) Communications System Ecological Monitoring Program: Summary of 1983 Progress. IIT Research Institute, Technical Report E06549-9, 1984, 49 pp. plus appendixes.
18. Zapotosky, J. E.; Abromavage, M. M. Extremely Low Frequency (ELF) Communications System Ecological Monitoring Program: Plan and Summary of 1982 Progress. IIT Research Institute, Technical Report E06516-6, 1983, 77 pp. plus appendixes.

ELF COMMUNICATIONS SYSTEM ECOLOGICAL MONITORING PROGRAM:  
BIRD SPECIES AND COMMUNITIES

ANNUAL REPORT: 1987-88  
SUBCONTRACT NUMBER: E06549-84-011

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ELF COMMUNICATIONS SYSTEM ECOLOGICAL MONITORING PROGRAM:

BIRD SPECIES AND COMMUNITIES

ANNUAL REPORT: 1987-88

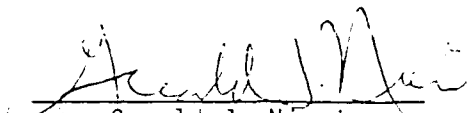
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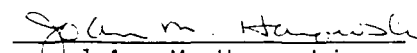
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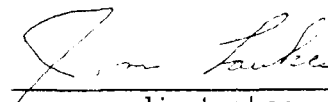
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## SUMMARY

This investigation was designed to isolate effects of electromagnetic (EM) fields produced by extremely low frequency (ELF) antenna systems on bird species breeding in or migrating through Wisconsin and Michigan. Specifically, we seek to determine if bird species richness and abundance differ between areas that are close to the antenna and those that are far enough away to be unaffected by the antenna. We are pursuing this question at both the community and species level. Characteristics examined include total species richness and abundance, abundances of common bird species, and abundances of birds within selected guilds. Our monitoring program includes bird censuses over a five month period from May to September, 1986-1988. Additional data were collected in June 1985 and in August 1984.

No consistent patterns have yet emerged to demonstrate that birds are more or less abundant on treatment relative to control segments in either state. Few significant differences have been found at the community or species level; differences in one season or year are not always repeated in subsequent year(s) or season(s). Differences between treatment and control segments, particularly in Michigan where the antenna only was operated periodically, are most likely due to habitat differences.

## ABSTRACT

This investigation was designed to isolate effects of electromagnetic (EM) fields produced by extremely low frequency (ELF) antenna systems on bird species breeding in or migrating through Wisconsin and Michigan. Specifically, we seek to determine if bird species richness and abundance differ between areas that are close to the antenna and those that are far enough away to be unaffected by the antenna. We are pursuing this question at both the community and species level. Characteristics examined include total species richness and abundance, abundances of common bird species, and abundances of birds within selected guilds. Our monitoring program includes bird censuses over a five month period from May to September (1986-1988). Additional data were collected in June of 1985 and August of 1984. Here we summarize results of our 1988 research activities. The Michigan transmitter operated approximately 8 hr/day, Monday through Friday, at 15 amperes from January through June and at 75 amperes after 15 July in 1988. We therefore consider 1988 a transitional year in terms of EM exposures at the Michigan facility.

Bird abundance and species diversity were highest in June in Michigan and in May in Wisconsin. Total number of individuals recorded per segment was higher on control than on treatment segments in Michigan in May; no other differences in community level parameters were significant in either state. Considerable annual variation in numbers of individuals and species was noted.

Particularly abundant species (all seasons included) included the Nashville Warbler, Ovenbird, White-throated Sparrow, Red-eyed Vireo, Black-capped Chickadee, and Golden-crowned Kinglet. The most abundant species present on treatment and control segments varied among seasons and between states. Among "abundant" species (>1 individual observed/500 m segment), seven of 34 comparisons (over all seasons) revealed a significant difference

between treatment and control segments in Michigan; five indicated a greater abundance on treatment segments. Two of 28 comparisons indicated a higher abundance on treatment segments in Wisconsin; no other comparisons were significant.

Previous analyses of vegetation on Wisconsin and Michigan study sites (Blake et al. 1988) revealed differences between treatment and control plots. The difference most likely to influence bird populations was distribution of coniferous and deciduous habitats. Treatment segments supported more coniferous and lowland habitats than did control areas, in both states.

To account for differences in habitat between treatment and control segments in Wisconsin, we paired treatment and control segments on the basis of habitat similarity and compared bird abundances on these paired segments (N = 15 pairs). (The Michigan study is designed as a "before-and-after" experiment and, thus, differences in habitat pose less of a problem for interpretation of bird distribution patterns.) Nine of 44 comparisons of abundant species showed significant differences between paired segments in Wisconsin; in seven cases, numbers were higher on treatment segments. Later analyses will consider effects of vegetation on results from previous years and on distribution patterns of less common species and guilds.

Twenty-four of 114 comparisons of common species (based on prominence values) between treatment and control segments (all segments) in Michigan and 14 of 90 in Wisconsin were significant. Values were higher on control segments in Michigan in 16 cases; 8 of 14 were more abundant on control than on treatment segments in Wisconsin.

Few species were consistently and significantly more abundant on either treatment or control segments among seasons within a year or within seasons between years. Differences between treatment and control segments,

particularly in Michigan where the antenna only was operated periodically, are most likely due to habitat differences.

Species were classified into guilds on the basis of foraging behavior and preferred breeding habitat. Abundances of birds within different guilds on treatment and control segments were compared during each season in 1988. Few significant differences were found between treatment and control segments. Differences were most consistent for habitat categories, providing further evidence that habitat differences are responsible for many of the observed differences in bird distribution patterns between treatment and control segments.

## INTRODUCTION

Effects of extremely low frequency (ELF) electromagnetic (EM) fields on most aspects of a bird species' life history are poorly understood (National Academy of Sciences 1977; Lee et al. 1979; other references in Hanowski et al. 1987). Several investigators have studied effects of transmission lines on structure and composition of bird communities; most have analyzed combined effects of habitat alteration and EM fields (Anderson et al. 1977; Anderson 1979; Dawson and Gates 1979; Meyers and Provost 1979; Stapleton and Kiviat 1979; Bell 1980; Bramble et al. 1984; Niemi and Hanowski 1984). Others have focused on effects of the right-of-way (ROW) edge (Chasko and Gates 1982; Kroodsma 1982), collision with lines (Beaulaurier et al. 1982), and audible noise generated by a transmission line (Lee and Griffith 1978). We are unaware, however, of any previous investigations that have attempted to separate effects of EM fields on bird species and communities from effects due to habitat changes along the ROW.

This investigation was designed to isolate effects of EM fields produced by ELF antenna systems on bird species breeding in or migrating through Wisconsin and Michigan. Specifically, we seek to determine if bird species richness and abundance differ between areas that are close to the antenna and those that are far enough away to be unaffected by the antenna. We are pursuing this question at both the community and species level. Characteristics examined include total species richness and abundance, abundances of common bird species, and abundances of birds within selected guilds.

Our study encompasses spring migration (May), early (June) and late (July) breeding, and early (August) and late (September) fall migration. In this report we summarize our research activities for 1988, our fifth year of participation in the ELF ecological monitoring program. This is the third

year in which censuses were conducted during all seasons (above). Potential effects of the ELF antenna on birds may vary among seasons. During migration, birds may be present on study areas for only brief periods. Conversely, breeding birds remain on territories for substantial periods of time, increasing their exposure to EM fields.

Two potential approaches are possible for assessing effects of the ELF antenna on bird communities. These are to (1) compare the affected area (treatment) with a similar control area; or (2) conduct a before-and-after study. Because our study was initiated in Michigan before the antenna began operation, we can conduct a before-and-after investigation in that state. The antenna was operated in Michigan in 1988 for about 8 hours on weekdays at a current strength of 15 amperes from January through June and at 75 amperes after 15 July. Full operation will be at 150 amperes on a continuous basis. Thus, we consider 1988 to be a transitional year. However, data are analysed in the same manner regardless of EM field impacts. Full operation at 150 amperes is expected to begin in September of 1990.

The antenna has been operating in Wisconsin periodically since 1969 and on a near continuous basis for the past several years. No pre-impact data on bird populations are available and, thus, we cannot assume that the antenna system has not already affected bird communities in Wisconsin. Consequently, we cannot compare transect segments based on similarities in bird species communities. We can, however, account for habitat differences in our analyses. By incorporating analyses of habitat, we will be able to more clearly isolate potential effects of the EM fields produced by the antenna. To this end, we conducted a detailed habitat assessment in 1986 and 1987 to document habitat differences and similarities between control and treatment segments in Wisconsin.

Our rationale for using habitat structure to compare areas is based on the fact that birds select breeding areas (and, to a lesser extent, migration stop-over points) largely on the basis of vegetation structure (Lack 1933; Hilden 1965; James 1971; Cody 1985). Areas of similar vegetation should also have similar bird communities. Although this study design is not as desirable as the before-and-after design in Michigan, studying potential effects in Wisconsin in concert with Michigan provides further insight into the potential long-term effects of the antenna on bird species and communities.

#### EXPERIMENTAL DESIGN

The experimental design for this project has been described previously in detail (Hanowski et al. 1987). Briefly, we sample birds along a series of linear transects located adjacent to (treatment) or away from (control) the ELF antenna. A discussion of the rationale for this procedure is in Appendix 1.

#### STUDY AREAS

Study areas were the same as in 1986 and are described in Appendix 1. Four 500-m transect segments (two treatment and two control) in Michigan were partially logged; logging affected about 5, 15, 45, and 65% of the four segments. Additional areas are likely to be affected before the project is completed (Table A2). However, in an agreement reached with Michigan Department of Natural Resources, most logging along the Michigan study transects will be delayed until 1992. Analyses of annual variation in bird community composition revealed that segments that experienced slight (< 5-15%) logging showed no greater difference between years than did unlogged sites (Blake et al., in review). Segments that were logged over all or most of their length showed significantly greater differences in bird species

composition between years than did unlogged segments. Consequently, our analyses of bird distribution patterns between years omit segments logged over more than 20% of their length.

## METHODS

Detailed methods employed in the investigation have been described previously (Hanowski et al. 1987) and are repeated in Appendix 1. Here we review the main points and describe any changes from previous years.

### BIRD CENSUSES

We censused birds using a line transect method (e.g., Jarvinen and Vaisanen 1975). Each 500 m segment (40 control and 40 treatment in each state) was censused during early May (spring migration and arrival of breeding residents), June (early breeding), July (late breeding), August (early fall migration), and September (late fall migration). Censuses were conducted from one half hour before to 4.5 hours after sunrise on days with little wind ( $<15$  km/hr) and little or no precipitation.

We randomly assigned censuses of control and treatment transects (eight 500 m segments/transect) to each of two observers, with the restriction that each observer census the same number of control (80) and treatment (80) segments in each month. Control and treatment transects were censused simultaneously by the two observers.

Eight transect segments were censused by each observer daily. Each observer walked at a rate of about 17 m/min (30 min/500 m segment) and recorded the following information for each bird that was observed (by sight or sound) within 100 m of the segment center line: (1) species; (2) sex, when possible; (3) behavior (e.g., singing or calling); and (4) location on the segment. We classified each species by (1) nesting area, (2) food or foraging



type, (3) breeding habitat preference, and (4) migration strategy (Appendix 2), using published sources (e.g., Martin et al. 1951; Bent 1963, 1964; Green and Niemi 1978; Terres 1982; AOU 1983; Blake and Karr 1984) and personal observations. Previous analyses (Blake et al. 1988) indicated that differences between treatment and control segments were most likely to occur among groups defined on the basis of foraging behavior and breeding habitat. Consequently, we used those guilds in analyses of the effects of the ELF antenna during 1988.

## VEGETATION

Methods for sampling vegetation are described in Appendix 1. Habitat variables used in Wisconsin are in Appendix 3; habitat categories used in Michigan are in Appendix 4. We completed sampling of vegetation at all Wisconsin segments during 1987. Vegetation was sampled at 21 points (every 25 m) along each 500 m transect segment. Detailed results of our habitat analyses were presented in Blake et al. (1988) and are not repeated here.

## STATISTICAL ANALYSES

### COMMUNITY PARAMETERS AND ABUNDANT SPECIES

We used the same criteria to select variables for parametric statistical analysis that we identified in 1985 (Niemi and Hanowski 1986): (1) those species with a mean of more than one observation per 500 m segment ("abundant species") in control or treatment areas of either state in any season; (2) mean number of species observed in a 500 m segment in control or treatment areas of either state and during each season; and (3) mean number of individuals observed in a 500 m segment in control or treatment areas of either state and during each season.

We used one-way ANOVA (Sokal and Rohlf 1981) to test for differences between control and treatment segments within a season. Annual differences were examined by season for number of species and individuals using a two-way ANOVA. (Separate papers will examine annual variation in abundance in more detail [e.g., for individual species] and we do not include such analyses in this report.) Because some segments were affected by logging after the initial census in 1985, we excluded logged segments in analyses of annual variation.

Variables used in parametric statistical tests were examined for normality (Wilk-Shapiro test; skewness and kurtosis) and homoscedasticity of variance (Bartlett's test) prior to statistical analyses (Sokal and Rohlf 1981). Variables were transformed where necessary (e.g., logarithmic, square root) to reduce skewness, kurtosis, and heterogeneity of variances. Nonparametric tests (Kruskal-Wallis ANOVA) were used for variables that did not meet assumptions, even after transformation.

#### EFFECTS OF HABITAT STRUCTURE: WISCONSIN

We used a paired sample approach to control for effects on bird populations of differences in habitat that exist between treatment and control segments in Wisconsin (see Blake et al. 1988 for analyses of vegetation). We paired treatment and control segments on the basis of habitat. We used a principal components analysis to reduce the 24 original variables (15 describing structural features of the habitat and 9 describing abundance of dominant tree species) to a smaller set of uncorrelated variables that explained a substantial amount of variation in habitat. The first 7 components had eigenvalues greater than 1.0 and explained 74% of the variation in habitat (Appendix 3). These components were used to calculate a Euclidean distance between each possible treatment-control pair:

$$D_{ij} = \left( \sum_{k=1}^7 (X_{ik} - X_{jk})^2 \right)^{0.5}$$

where  $D_{ij}$  is the distance between segments  $i$  and  $j$  and  $X_{ik}$  and  $X_{jk}$  are weighted values for principal component  $k$  (for  $k = 7$  components) for segments  $i$  and  $j$ . Distances were calculated with each component weighted by the amount of variation it explained.

We calculated the nearest neighbor distance (i.e., most similar treatment [or control] segment to the control [or treatment] segment being compared) for each segment ( $N = 80$  nearest neighbor distances). These distances were used to determine the mean nearest neighbor distance among all pairs. We then selected those treatment-control segment pairs that were separated by a distance that was less than the mean nearest neighbor distance among all segments. A total of 15 segment pairs met this criterion. We then used a paired sample test (t-test or Wilcoxon matched pairs signed ranks test) to compare differences in bird abundances between treatment and control segments. Here we report results from 1988 only. Later we will reexamine results from previous years (1985-1987) in a similar fashion.

## COMMON SPECIES

A second group of less abundant species ("common species") was chosen based on frequency of occurrence. These species had to be present on at least six segments during a season with the restriction that they occur on at least five control or five treatment segments (e.g., a species was not included if it occurred on three control and three treatment segments).

A prominence value was calculated for each species using the formula:

$$PV = D * F^{0.5}$$

where  $D$  = number of individuals observed and  $F$  = the relative frequency of species occurrence on treatment or control segments. Prominence values were calculated for control and treatment segments separately and differences were

tested with a goodness of fit G-test or binomial test (Sokal and Rohlf 1981). The prominence value weights both the frequency of occurrence and number of individuals (Beals 1960; Blake 1982) and thus is preferable to using either total number of individuals observed or number of segments on which a species was observed to test for differences between control and treatment areas. Differences between these methods were more fully explored in the previous report (Hanowski et al. 1987). Briefly, fewer significant differences are achieved using prominence values than comparisons based on individuals but more than when frequency of occurrence is used.

#### EDGE EFFECTS

Previous analyses have considered the possibility that differences between treatment and control segments were due to edge effects related to the right-of-way corridor. We found no indication that such an effect exists (Hanowski et al. 1987, Blake et al. 1988) and do not consider the question in this report.

#### PROBABILITY VALUES

To simplify and condense the results section, we eliminated all probability ( $P$ ) values from the text. Any difference stated in this section was significant to at least the  $P < 0.05$  level.

### RESULTS

#### SPECIES RICHNESS AND ABUNDANCE OF INDIVIDUALS

##### 1988 results

Total number of species and individuals observed varied among seasons on control and treatment transects in both states (Tables 1, 2). Number of observations for all species are in Appendix 5. Total abundance was highest

Table 1. Total numbers of individuals (indiv.) and species observed on treatment (T) and control (C) transects in Michigan and Wisconsin, 1985-1988. A combined species total for treatment and control segments is in parentheses.

		1985		1986		1987		1988	
		T	C	T	C	T	C	T	C
<u>MICHIGAN</u>									
May:									
indiv.				949	1210	775	888	815	939
species				54 (76)	69	50 (67)	62	53 (66)	56
June:									
indiv.	1629	1327		1098	1169	1131	1162	1061	1014
species	70 (81)	72		60 (74)	68	71 (81)	73	70 (89)	77
July:									
indiv.				938	978	1136	1258	891	907
species				59 (75)	63	68 (81)	73	69 (83)	68
August:									
indiv.				380	478	682	610	564	469
species				53 (61)	46	59 (68)	54	50 (66)	51
September:									
indiv.				402	627	634	501	469	574
species				36 (55)	48	46 (55)	41	46 (60)	47
<u>WISCONSIN</u>									
May:									
indiv.				1396	1452	1305	1302	1105	1142
species				67 (78)	62	72 (83)	62	68 (82)	69
June:									
indiv.	1548	1348		1207	1050	1358	1439	818	839
species	76 (81)	66		66 (72)	57	69 (76)	65	68 (82)	62
July:									
indiv.				858	808	861	761	644	693
species				50 (64)	54	66 (81)	63	53 (67)	55
August:									
indiv.				522	477	606	653	400	461
species				40 (47)	38	51 (63)	50	47 (57)	44
September:									
indiv.				682	644	819	880	403	426
species				31 (48)	39	46 (56)	42	36 (50)	43

Table 2. Mean observations in a 500m segment on control (C) and treatment (T) segments, 1985-88. Significance of one-way ANOVAs between treatment and control segments is shown for each year. For two-way ANOVAs, T=treatment effect, Y=year effect, and I=interaction. Two-way ANOVAs were calculated with logged segments excluded.

Month	1985		1986		1987		1988		ANOVA		
	T	C	T	C	T	C	T	C	T	Y	I
<u>MICHIGAN</u>											
May:											
Indiv.			23.7**	30.3	19.4	22.2	20.4	23.5	***	***	
species			9.7**	12.9	8.1**	10.8	9.5	11.0	***	*	
June:											
Indiv.	40.8**	33.3	27.5	29.2	28.3	29.1	25.5	25.4	***	**	
species	14.2	14.0	11.1	12.5	12.5	12.9	12.4	13.1	**		
July:											
Indiv.			23.5	24.5	23.4	31.5	22.1	22.7	*	***	
species			9.5	10.4	11.3	14.4	11.1	11.0		***	
August:											
Indiv.			9.6	12.0	17.1	15.3	14.1	11.7	***		
species			4.6	5.2	7.3	6.7	6.1	5.3	**		
September:											
Indiv.			10.1	15.7	15.0	12.5	11.7	14.4		*	
species			4.0	5.6	5.4	5.1	5.0	5.6		*	
<u>MISSISSIPPI</u>											
May:											
Indiv.			34.9	36.3	32.6	32.5	27.6	28.5	***		
species			13.4	12.8	13.1	12.2	13.3	13.5			
June:											
Indiv.	38.7**	33.8	30.2	26.3	34.0	35.0	20.5	21.0	***	**	
species	15.0*	13.0	12.3	11.3	14.3	14.4	11.4	10.6	***		
July:											
Indiv.			21.5	20.2	21.5	19.0	16.1	17.3	**		
species			8.4	7.8	9.7	8.3	7.7	7.9	**		
August:											
Indiv.			13.1	12.2	15.2	15.3	10.0	11.5	***		
species			5.3	4.8	5.8	5.5	4.6	4.6	**		
September:											
Indiv.			17.1	16.0	20.5	22.0	10.1	10.7	***		
species			5.3	5.3	6.1	6.8	4.1	4.2	***		

\*  $P < 0.05$ ; \*\*  $P < 0.01$ ; \*\*\*  $P < 0.001$

during June in Michigan and in May in Wisconsin (Table 1). Part of the difference between states was due to differences in census date; Wisconsin sites were sampled 7 to 10 days after Michigan. Trends in abundance between treatment and control segments were not consistent (i.e., always greater on treatment or on control segments) across seasons in Michigan but were in Wisconsin (Table 2). Mean number of individuals observed per segment was greater on control segments in Michigan in May, but no other differences were significant (Table 2). When we based comparisons of individuals on paired treatment and control segments in Wisconsin (Table 5), mean number of individuals observed was greater on control segments in July. Differences between treatment and control segments were not significant in other months (Table 5).

Patterns in the abundance of species generally followed those for individuals (Table 2). Species richness was highly correlated with individuals per segment in Michigan ( $r = 0.98$ ) and Wisconsin ( $r = 0.99$ ). Mean number of species recorded per 500 m segment did not differ between treatment and control segments in any season (Table 2). No significant differences in number of species were noted between paired segments in Wisconsin (Table 5).

#### Annual variation in species and individuals

Considerable annual variation in abundance of individuals and species was noted in both states (Tables 2, 3). Abundance tended to be lowest in 1986 and, especially in 1988 in Wisconsin (Table 3). Treatment effects were noted in Michigan during May (individuals and species) and July (species only; Table 2); individuals and species were more abundant on controls. No treatment effects were noted in Wisconsin during any season when results from all years were included in the analyses (Table 2).

Table 3. Summary of differences among years and among treatment (T) and control (C) segments, by year (85, 86, 87, 88). (See Table 2 for ANOVA results.) Year and segment combination (e.g., C86 = control segments in 1986) are arranged from left to right in decreasing order of abundance. Year- segment combination not underlined by the same line are significantly different ( $P < 0.05$ ). For example, for individuals in Michigan in May, abundance was higher on control segments in 1986 than at any other time; other periods did not differ.

Month	Abundance of Individuals	Abundance of Species
<u>Michigan</u>		
May	<u>C86 T86 C88 C87 T88 T87</u>	<u>C86 C88 C87 T88 T86 T87</u>
June	<u>T85 C85 C87 C86 T87 T86 T88 C88</u>	<u>T85 C85 C88 C87 T87 C86 T88 T86</u>
July	<u>C87 T87 C86 T86 C88 T88</u>	<u>C87 T87 C88 T88 C86 T86</u>
August	<u>T87 C87 T88 C88 C86 T86</u>	<u>C87 T87 C88 T88 C86 T86</u>
September	<u>C86 T87 C88 C87 T88 T86</u>	<u>C86 T87 C88 C87 T88 T86</u>
<u>Wisconsin</u>		
May	<u>C86 T86 C87 T87 C88 T88</u>	<u>C88 T86 T87 T88 C86 C87</u>
June	<u>T85 C87 C85 T87 T86 C86 C88 T88</u>	<u>C87 T87 T85 C85 T86 T88 C86 C88</u>
July	<u>T86 T87 C86 C87 C88 T88</u>	<u>T87 C87 T86 C88 C86 T88</u>
August	<u>C87 T87 T86 C86 C88 T88</u>	<u>C87 T87 T86 C88 T88 C86</u>
September	<u>C87 T87 T86 C86 C88 T88</u>	<u>C87 T87 C86 T86 C88 T88</u>



## DISTRIBUTION OF ABUNDANT SPECIES

### Spring migration

The White-throated Sparrow was the most abundant species on treatment and the Nashville Warbler on control segments in Michigan (Appendix 5a). Nine species were recorded with an average abundance of at least one bird per segment (treatment or control) in Michigan, but only Yellow-bellied Sapsucker showed a significant difference (more abundant on controls) between controls and treatments (Table 4). The Ovenbird was the most abundant species in Wisconsin on both control and treatment segments (Appendix 5b). The Chestnut-sided Warbler was more abundant on treatment segments in Wisconsin (Table 4), but no other abundant species (11 total) showed a significant difference in abundance between treatment and control segments. When comparisons were based on paired treatment and control segments, three species were more abundant on treatment and one on control segments in Wisconsin (Table 5).

### Early breeding

The Ovenbird was the most abundant species in June in both states and on both control and treatment segments (Appendices 5a, 5b). Chestnut-sided Warbler and White-throated Sparrow were more abundant on treatment segments in Michigan; Chestnut-sided Warblers were more abundant on treatment segments in Wisconsin (Table 4). No other abundant species showed a significant difference in abundance between treatment and control segments. Two species showed significant differences when comparisons were based on paired segments (Table 4); Red-eyed Vireo was more common on treatment and Nashville Warbler on control segments. No difference, however, was noted for Chestnut-sided Warblers.

Table 4. Mean number of individuals per segment for abundant species (those with an average of at least one individual per treatment or control segment) that showed a significant difference (one-way ANOVA) in abundance between treatment (T) and control (C) segments in 1988.

Species	Michigan		Wisconsin	
	T	C	T	C
<u>MAY<sup>1</sup></u>				
Yellow-bellied Sapsucker	0.5	** 1.4		
Chestnut-sided Warbler			2.0	* 1.1
<u>JUNE<sup>2</sup></u>				
Chestnut-sided Warbler	1.6	* 0.6	1.8	* 1.3
White-throated Sparrow	1.9	* 0.9		
<u>JULY<sup>3</sup></u>				
Black-capped Chickadee	0.6	* 1.6		
Golden-crowned Kinglet	1.4	* 0.7		
Chestnut-sided Warbler	1.1	* 0.4		
White-throated Sparrow	1.8	** 0.6		
<u>AUGUST<sup>4</sup></u>				
<u>SEPTEMBER<sup>5</sup></u>				

<sup>1</sup> Species tested: 9 in Michigan; 11 in Wisconsin.

<sup>2</sup> " " 9 " " 6 " "

<sup>3</sup> " " 8 " " 5 " "

<sup>4</sup> " " 3 " " 1 " "

<sup>5</sup> " " 5 " " 5 " "

\* P < 0.05; \*\* P < 0.01

Table 5. Mean number of species and individuals on all treatment (T) and control (C) segments and on paired segments in Wisconsin in 1988. Treatment and control segments were paired (N = 15 pairs) on the basis of habitat. Differences between paired segments were tested with paired t-tests or Wilcoxon matched pairs signed rank test (WSRT) for non-normal data. Mean values are given for species only if they showed a significant difference between paired segments. See Tables 2 and 4 for results based on all segments.

Species	All Segments		Paired Segments			
	T	C	T	C	t-test	WSRT
<u>MAY<sup>1</sup></u>						
Total species	13.3	13.6	15.5	13.5		
Total individuals	27.6	28.6	25.0	26.5		
Red-eyed Vireo	1.0	1.1	1.6	0.5		*
Chestnut-sided Warbler	2.0	1.1	2.6	1.2	*	
Black-throated Green Warbler	1.8	1.7	2.6	1.1		*
Black-and-white Warbler	0.9	1.1	0.8	1.5	*	
<u>JUNE<sup>2</sup></u>						
Total species	11.4	10.6	14.3	12.4		
Total individuals	20.5	21.0	17.5	21.1		
Red-eyed Vireo	1.4	1.5	1.3	0.6		*
Nashville Warbler	0.9	1.4	0.9	2.3	*	
<u>JULY<sup>3</sup></u>						
Total species	7.7	7.9	9.8	9.1		
Total individuals	16.1	17.3	14.7	18.5	*	
Hermit Thrush	1.6	1.4	2.5	1.4		*
Red-eyed Vireo	1.5	2.0	2.2	1.1	**	
Black-throated Green Warbler	1.2	1.0	1.5	0.6		*
<u>AUGUST<sup>4</sup></u>						
Total species	4.6	4.6	6.4	6.2		
Total individuals	10.0	11.5	8.7	13.2		
<u>SEPTEMBER<sup>5</sup></u>						
Total species	4.1	4.2	5.3	5.3		
Total individuals	10.1	10.7	12.4	10.8		

<sup>1</sup> 12 species tested.

<sup>2</sup> 12 species tested.

<sup>3</sup> 7 species tested.

<sup>4</sup> 7 species tested.

<sup>5</sup> 6 species tested.

\* P < 0.05; \*\* P < 0.01

### Late breeding

The Ovenbird was the most abundant species in Michigan and the Red-eyed Vireo in Wisconsin (Appendices 5a, 5b). Four species in Michigan (Black-capped Chickadee, Golden-crowned Kinglet, Chestnut-sided Warbler, White-throated Sparrow) showed a significant difference in abundance between treatment and control segments (Table 4); all but the chickadee were more abundant on treatment segments. No abundant species showed a significant difference between treatment and control segments in Wisconsin in July when comparisons were based on all segments. Three species, however, were more abundant on treatment segments when comparisons were based on paired segments (Table 4). Total individuals, however, were more abundant on control segments when comparisons were based on paired segments (Table 4).

### Early fall migration

Bird communities were dominated by Black-capped Chickadees (both states) and Golden-crowned Kinglets (Michigan) during early fall migration (Appendices 5a, 5b). No abundant species in either state showed a significant difference in abundance between control and treatment segments (Tables 4, 5).

### Late fall migration

Black-capped Chickadee was the most abundant species in both states on both treatment and control segments (Appendices 5a, 5b). No abundant species in either state showed a significant difference in abundance between control and treatment segments (Tables 4, 5).

## DISTRIBUTION PATTERNS OF COMMON SPECIES

Abundances of common species (as indexed by prominence values) differed between treatment and control transects in 24 of 114 comparisons during 1988

in Michigan (Table 6). In 16 cases, prominence values were higher on control than on treatment segments (Table 6). Five species (Brown Creeper, Ovenbird, Song Sparrow, Yellow-bellied Sapsucker, and American Robin) showed a significant difference in more than one season. In all cases, differences were in the same direction (i.e., always more abundant on control [Brown Creeper, Ovenbird, Yellow-bellied Sapsucker] or treatment [Song Sparrow, American Robin] segments) (Table 6).

Fourteen of 90 comparisons of common species showed significant differences between control and treatment transects during 1988 in Wisconsin (Table 6). In eight comparisons, prominence values were higher on control segments (Table 6). Only the Chipping Sparrow showed a significant difference in two seasons and was more abundant on treatments.

#### GUILD COMPOSITION

Few significant differences (5 of 50 tests) between treatment and control segments existed in abundance of different foraging guilds (Table 7). Birds feeding on bark insects were more common on control segments in Michigan in June and July, but no other foraging guild showed a significant difference in more than one season (Table 7).

Differences were more pronounced among habitat guilds (14 of 60 tests; Table 7). Birds preferring deciduous forest habitats were more common on control segments in Michigan and Wisconsin; the reverse was true for birds preferring coniferous habitat (Table 7). Birds preferring early successional habitat were more abundant on treatment segments in three months in Michigan; differences were not as pronounced in Wisconsin (Table 7).

Table 6. Prominence values (see text) for species showing significant differences (G-test) between treatment (T) and control (C) segments in 1988.

Species	Michigan		Wisconsin	
	T	C	T	C
<u>MAY<sup>1</sup></u>				
Blue Jay	10.5	** 29.0		
Brown Creeper	0.2	* 6.3		
Ruby-crowned Kinglet	12.1	* 3.5		
Black-throated Green Warbler	8.2	** 25.4		
Black-and-white Warbler	0.8	* 8.2		
Ovenbird	0.2	** 6.6		
Chipping Sparrow			8.1	* 1.1
Song Sparrow	13.6	** 1.9		
Red-winged Blackbird	1.3	*** 14.2		
<u>JUNE<sup>2</sup></u>				
Eastern Wood-Pewee			0.2	* 5.9
Least Flycatcher			2.2	* 9.2
Red-breasted Nuthatch			11.8	* 3.1
Winter Wren	3.5	** 18.3		
Hermit Thrush			12.0	* 24.8
Blackburnian Warbler			0.4	* 5.4
Chipping Sparrow	16.3	** 3.1	7.5	** 0.4
Song Sparrow	7.0	* 0.7	11.0	* 3.1
Brown-headed Cowbird	0.2	* 4.2		
<u>JULY<sup>3</sup></u>				
Ruffed Grouse	0.4	** 8.9		
Yellow-bellied Sapsucker	2.7	** 14.8		
Blue Jay			5.2	* 15.9
Brown Creeper	1.6	** 11.0		
American Robin	21.4	*** 2.9		
Northern Parula	0.4	** 7.6		
Chestnut-sided Warbler			17.2	*** 1.1
Common Yellowthroat	0.7	* 7.1		
<u>AUGUST<sup>4</sup></u>				
Brown Creeper			3.5	*** 19.6
American Robin	10.4	* 1.9		
Cedar Waxwing	22.0	*** 1.4	1.4	** 11.6
<u>SEPTEMBER<sup>5</sup></u>				
Ruffed Grouse			4.5	* 13.7
Yellow-bellied Sapsucker	1.1	** 9.0		
Red-breasted Nuthatch	11.4	* 25.4		
Ruby-crowned Kinglet			4.2	* 0.2
Ovenbird	3.3	* 11.0		
White-throated Sparrow	18.1	* 6.3		

<sup>1</sup> Species tested: 26 in MI; 22 in WI.<sup>2</sup> Species tested: 28 in MI; 27 in WI.<sup>3</sup> Species tested: 30 in MI; 17 in WI.<sup>4</sup> Species tested: 16 in MI; 13 in WI.<sup>5</sup> Species tested: 14 in MI; 11 in WI.

\* P &lt; 0.05; \*\* P &lt; 0.01; \*\*\* P &lt; 0.001

Table 7. Mean number of individuals in foraging and habitat guilds recorded on control (C) and treatment (T) segments in Michigan and Wisconsin during 1988. Means are given for foraging and habitat groups only if one-way ANOVA indicated a significant difference between treatment and control segments in at least one month.

Guild	Month	Michigan		Wisconsin	
		T	C	T	C
<u>Foraging guilds</u>					
Foliage insects	June	12.7	* 10.9		
Bark insects	June	0.6	* 1.2		
	July	0.5	* 1.2		
Ground invertebrates	June			3.2	* 4.7
Ground invertebrates and seeds	June			2.7	* 1.6
<u>Habitat guilds</u>					
Deciduous forest	May	3.8	* 6.3		
	June	8.3	* 11.2		
	July	6.9	* 9.7	4.6	* 6.9
Coniferous forest	June	2.7	* 1.8	1.6	* 1.1
	September			2.4	* 1.2
Lowland coniferous	May	0.6	* 1.1		
Mixed deciduous and coniferous	June			4.0	* 5.2
Early successional	June	4.9	** 2.2		
	July	4.2	*** 1.9	2.4	* 1.7
	August	1.4	*** 0.4	0.4	* 1.2

## DISCUSSION

### SPECIES DISTRIBUTION AND ABUNDANCE PATTERNS

No consistent patterns have yet emerged to demonstrate that birds are more or less abundant on treatment relative to control segments in either state. Few significant differences have been found at the community or species level; differences in one season or year are not always repeated in subsequent year(s) or season(s).

Differences between treatment and control segments are most noticeable in Michigan during May; species (Fig. 1) and individuals (Fig. 2) always were more abundant on control than on treatment segments. Patterns are less consistent in subsequent months, however. Individuals were significantly more abundant on treatment segments in June 1985 and on control in September 1986, but no other significant differences have been demonstrated at the community level (Table 2, Figs. 1, 2).

The Michigan facility was operated well below full strength in 1987 and half of 1988 (15 amperes, 8 hr/day, weekdays, starting June 1 1987 through 2 July 1988) and at 75 amperes (8 hr/day, weekdays) for the remainder of 1988. There has been, however, little noticeable change in bird populations on treatment relative to control segments. Populations were lower overall in 1988 relative to 1987, but as this decline occurred on both treatment and control segments, it is more likely attributable to some factor other than the antenna operation. 1988 was extremely dry and hot (pers. obs.) and the weather conditions may have had an adverse impact on birds (e.g., reduced reproductive success; early emmigration from study areas). Such a possibility is supported by the observation that abundances in May were almost identical in 1987 and 1988, but were lower in 1988 in subsequent months in both control and treatment areas (Figs. 1, 2).



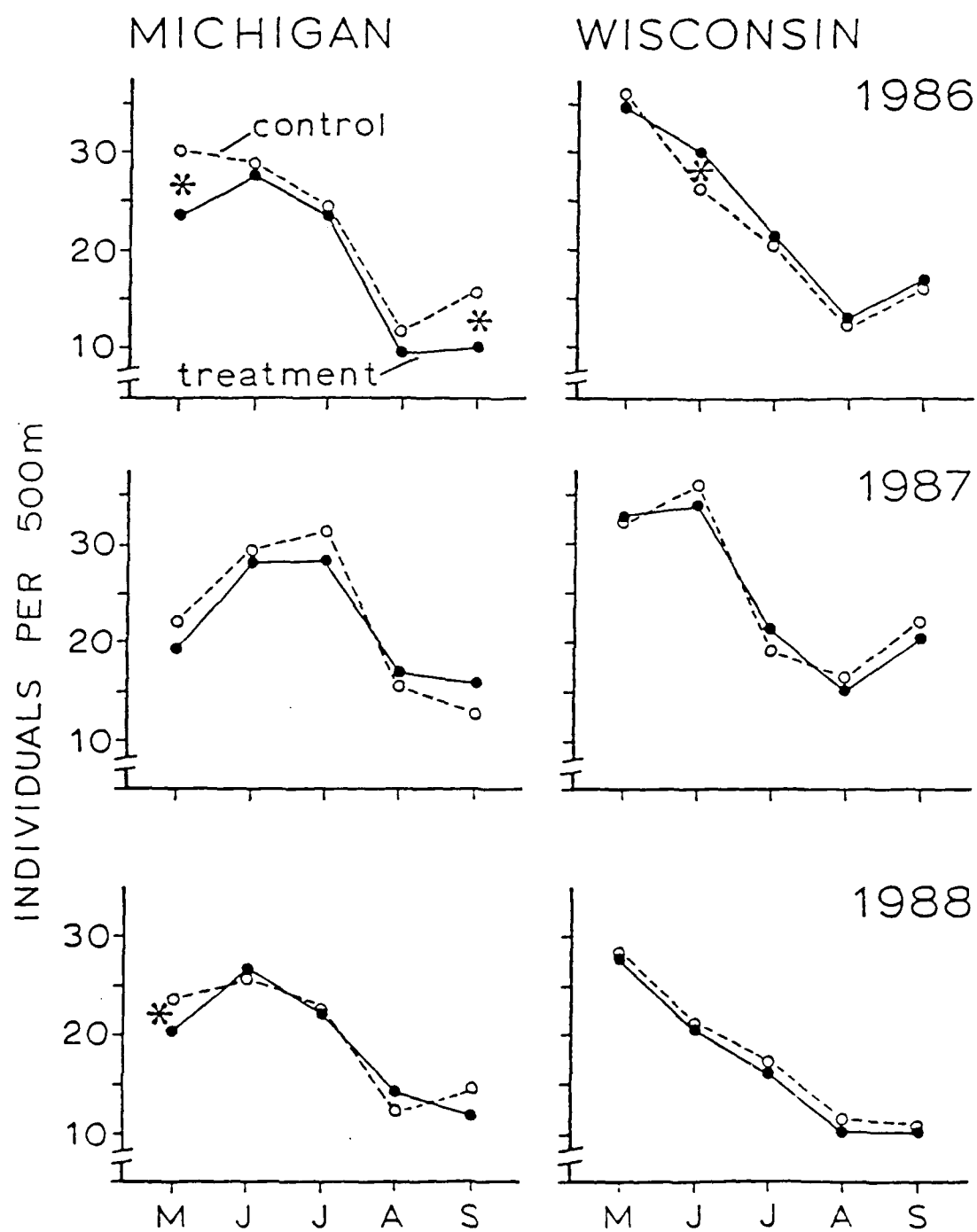


Figure 1. Mean number of individuals recorded per 500 m on treatment and control segments, 1986-1988.

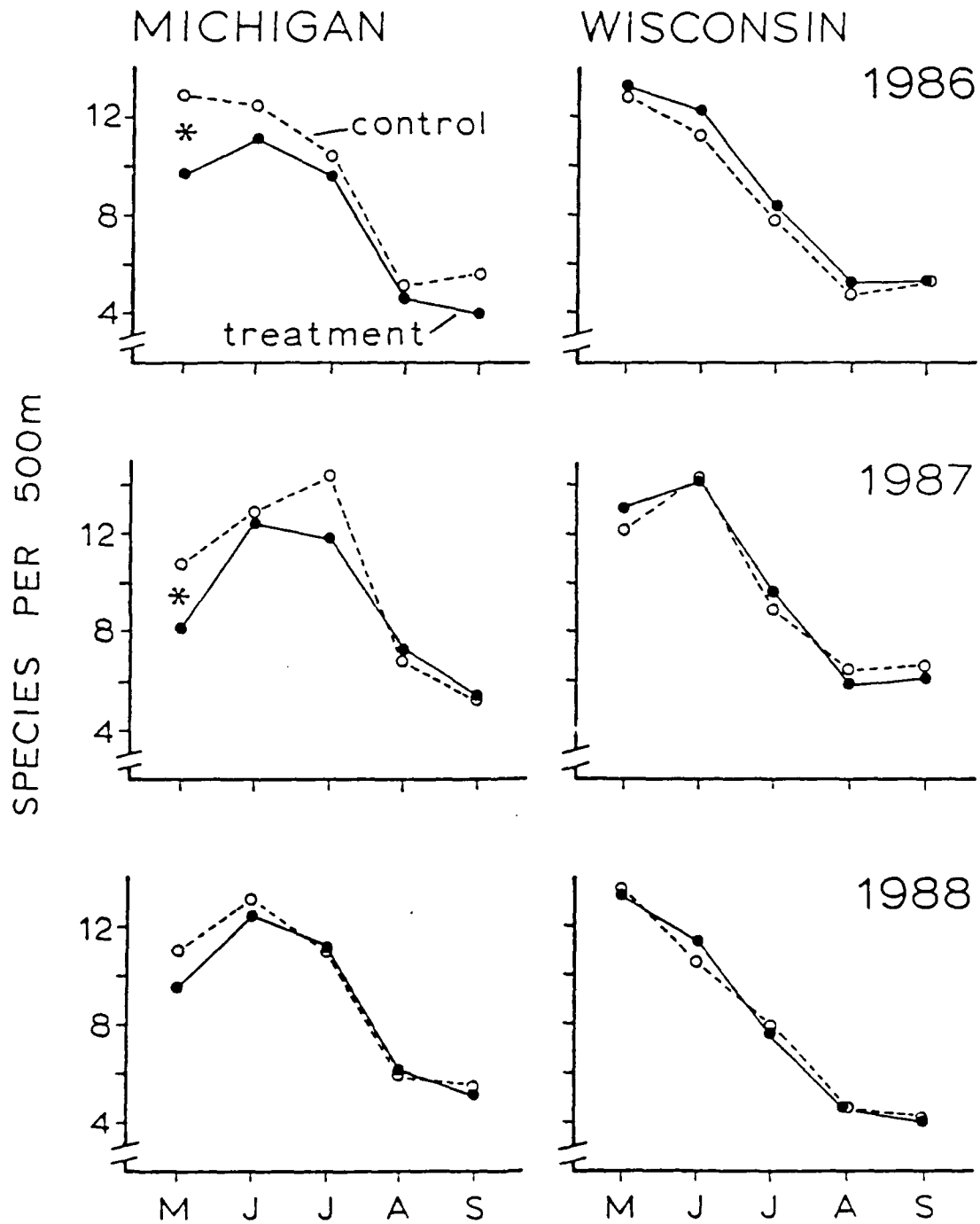


Figure 2. Mean number of species recorded per 500 m on treatment and control segments, 1986-1988.

Results from Wisconsin showed little consistency between years or among seasons in species richness or number of individuals. If the ELF transmitter was strongly influencing bird distribution patterns, one might expect that relative abundance of birds on treatment and control segments would remain the same from one year to the next, particularly during the breeding season, and from one season to the next. There was, however, little evidence for such an effect (Table 2, Figs. 1, 2). Species and individuals were more abundant on treatment segments in 1985 and individuals in 1986, but no other significant difference at the community level has been noted. In fact, throughout 1986-1988, species richness and abundance of individuals have been remarkably similar on treatments and controls (Figs. 1, 2).

The potential effect of the dry conditions in 1988 is seen in the generally lower values for 1988 relative to 1987. The fact that bird populations were lower in both states in 1988 provides further support for the suggestion that operation of the Michigan facility had little immediate effect on bird populations in that state.

#### Annual variation in abundance

Substantial variation occurred among years in abundance of many bird species (Figs. 1, 2). Overall, abundance has tended to decline from 1985 to 1988. Causes of such variation largely are unknown but likely are related to weather; 1988 was an exceptionally dry year and followed two relatively dry years (1986-1987). A preliminary analysis of annual variation in bird populations is currently under review (Blake et al., in review). By the completion of this project we will be able to analyze such variation in much greater detail.

A potentially confounding factor in examination of annual variation in bird communities relates to sampling. Particularly during spring migration,

changes in weather may profoundly influence the abundance of birds in a particular area (Richardson 1978). Differences in weather from one year to the next may produce apparent (as well as real) differences in abundance of birds. We attempt to minimize this problem by sampling over a five to six day period each season. Thus, weather patterns may not be as likely to strongly influence results of that sample. Similarly, we attempt to sample each season during the same calendar time period each year. It is likely, however, that differences of as much as a week from one year to the next have a considerably smaller influence on abundance than differences that may occur as a consequence of weather.

#### Guild distribution patterns

Species that belong to the same "guild" share some biological characteristics. Thus, if the ELF antenna system influences distributions of bird species we might expect members of a particular guild to be influenced in a similar fashion. Similarly, habitat related effects may be evident from the distribution patterns of guild members.

Relatively few differences in abundance of birds in different guilds were noted between treatment and control segments in either state in 1988 or previous years (Blake et al. 1988). Differences that did exist likely reflected differences in habitat that occur between treatment and control segments. Treatment segments in Michigan support more early successional habitat than do control areas and birds breeding in such habitats showed the strongest treatment effect, being more abundant in treatment segments. A similar result was noted for earlier years (Blake et al. 1988). Deciduous forest habitat is more common on control and coniferous on treatment segments in both states (Blake et al. 1988); distribution of birds preferring deciduous or coniferous habitat followed a similar trend.

Few consistent patterns have emerged with respect to distribution of individuals in different foraging guilds. Birds feeding primarily on foliage insects were more abundant on Michigan treatment areas in June 1988; a similar result obtained in 1985 but not in 1986 or 1987. In contrast, birds feeding on bark insects, while more common on Michigan control sites in 1988, showed no such pattern in earlier years (Blake et al. 1988). Birds foraging for invertebrates and seeds on the ground were, however, more abundant on Wisconsin treatment segments during June of 1985, 1986, and 1988.

#### Individual species

Habitat or EM related differences that exist between treatment and control segments may not influence all bird species in the same manner. If some species are more abundant on control and others on treatment segments, then such differences might cancel each other, producing nonsignificant results at the community level. If differences between treatment and control segments (either related to habitat or EM fields) are primary factors influencing distribution patterns of individual species, then we might expect those species to show similar patterns among years and seasons.

There have been relatively few cases where differences in abundance of a species between treatment and control segments have remained consistently significant among seasons and years (Tables 8, 9). A total of 39 species in Michigan and 35 in Wisconsin have shown a significant difference in abundance between treatment and control segments in at least one season and year (Tables 8, 9). Somewhat more species (21) were more abundant on control than on treatment segments (11) in Michigan (Table 8). The number of species showing a difference in Wisconsin was equally split between treatment (15 species) and control (16 species) segments (Table 9). However, many species have shown a significant difference in only one season in one year (16 species in Michigan;

Table 8. Summary by year and month\* of species that were significantly more abundant on treatment or control segments in Michigan. Underlined months indicate that differences were tested by ANOVA (i.e., "abundant" species; see text). Differences for common species (not underlined) were based on goodness-of-fit G-tests.

Species	More abundant on treatment				More abundant on control			
	1985	1986	1987	1988	1985	1986	1987	1988
Yellow-bellied Flycatcher	Ju	Ju	Ju					
Golden-crowned Kinglet	Ju		<u>S</u>	<u>Jy</u>				
Hermit Thrush		<u>Jy</u>						
American Robin	Ju			JyA				
Cedar Waxwing				A				
Golden-winged Warbler			Ju					
Nashville Warbler	<u>Ju</u>	<u>JuJy</u>	<u>Jy</u>					
Chestnut-sided Warbler	<u>Ju</u>			<u>JuJy</u>				
Mourning Warbler	<u>Ju</u>							
Rose-breasted Grosbeak	<u>Ju</u>	M						
White-throated Sparrow	<u>Ju</u>	S	<u>JuJyA</u>	<u>JuJyS</u>				
Blue Jay		Ju				S		M
Black-capped Chickadee				<u>Jy</u>			<u>MJu</u>	
Winter Wren				M	Ju	M		Ju
Yellow-rumped Warbler	Ju	Ju				S		
Chipping Sparrow	Ju			Ju		M		
Song Sparrow				MJu	Ju			
American Woodcock							Jy	
Ruffed Grouse					Jy		Jy	Jy
Yellow-bellied Sapsucker					M		<u>MJyA</u>	<u>MJyS</u>
Downy Woodpecker					A			
Eastern Wood-Pewee							A	
Least Flycatcher					Jy			
Great Crested Flycatcher							Ju	
Brown Creeper							Jy	<u>MJy</u>
Red-breasted Nuthatch								S
Veery							Jy	
Northern Parula								Jy
Black-throated Green Warbler							<u>M</u>	M
Blackburnian Warbler							Ju	
Black-and-white Warbler							M	M
American Redstart					M			
Ovenbird					S			
Common Yellowthroat					<u>MS</u>		M	<u>MS</u>
Swamp Sparrow					<u>JuJy</u>		Jy	Jy
Red-winged Blackbird							<u>MJy</u>	
Brown-headed Cowbird					<u>MJu</u>		<u>MJuJy</u>	M
Purple Finch					<u>MJu</u>			Ju

\* M - May; Ju - June; Jy - July; A - August; S - September.

Table 9. Summary by year and month\* of species that were significantly more abundant on treatment or control segments in Wisconsin. Differences in habitat structure between treatment and control segments have not been incorporated in these results; see Tables 5, 6 for 1988 results. Underlined months indicate that differences were tested by ANOVA (i.e., "abundant" species; see text). Differences for common species (not underlined) were based on goodness-of-fit G-tests.

Species	More abundant on treatment				More abundant on control			
	1985	1986	1987	1988	1985	1986	1987	1988
Alder Flycatcher	Ju							
Red-breasted Nuthatch			<u>Jy</u>	Ju				
Golden-crowned Kinglet		Ju	Jy					
Nashville Warbler		A						
Chestnut-sided Warbler	<u>Ju</u>		<u>Ju</u>	<u>MJuJy</u>				
Magnolia Warbler		M	M					
Cape May Warbler		M						
Yellow-rumped Warbler	Ju							
Common Yellowthroat		M						
Indigo Bunting		Ju						
Chipping Sparrow	Ju	Ju	Ju	MJu				
Song Sparrow		M		Ju				
Swamp Sparrow	Ju	Ju	Jy					
White-winged Crossbill			Jy					
Evening Grosbeak	Ju							
Blue Jay			<u>M</u>			Jy		Jy
Ruby-crowned Kinglet				S			A	
Hermit Thrush		A						Ju
American Robin	Ju						Ju	
Ruffed Grouse					Ju	S		S
Eastern Wood-Pewee							Ju	Ju
Yellow-bellied Flycatcher					<u>Ju</u>			
Least Flycatcher					<u>Ju</u>		M	Ju
Great Crested Flycatcher					<u>Ju</u>	Ju	M	
Brown Creeper								A
Winter Wren					Ju		Jy	
Veery						Ju		
Cedar Waxwing								A
Red-eyed Vireo							A	
Northern Parula						<u>M</u>		
Blackburnian Warbler								Ju
Black-and-white Warbler					<u>M</u>			
Ovenbird					Jy		<u>JuJy</u>	
Canada Warbler					Ju		M	
Rose-breasted Grosbeak					MJu		M	

\* M - May; Ju - June; Jy - July; A - August; S - September.

16 in Wisconsin). Moreover, six species in Michigan and four in Wisconsin have been more abundant on treatment segments in one season and on control segments in another (Tables 8, 9). For example, the Yellow-rumped Warbler was more abundant on treatment segments in June 1985 and 1986 in Michigan but was more common on control segments during fall migration (September, Table 8). Such reversals may reflect seasonal changes in habitat selection.

Several species have shown a consistent pattern of distribution between treatment and control segments. Yellow-bellied Flycatchers in Michigan, for example, have been more abundant on treatment segments in three of four Junes sampled (Table 8). White-throated Sparrows also have been consistently more abundant on treatment segments. Several species (e.g., Yellow-bellied Sapsucker, Ruffed Grouse, Black-and-white Warbler) consistently have been more abundant on control segments during one month. Similarly, in Wisconsin, the Chestnut-sided Warbler was more abundant on treatment segments in three June samples and the Chipping Sparrow in all four (Table 9).

Differences in abundance of species that showed a consistent difference between treatment and control segments likely are related to habitat in many cases. White-throated Sparrows, for example, favor early successional habitats. Such habitats were more common on treatment segments than on controls in Michigan. In contrast, deciduous woods are more common on control segments in Michigan (and Wisconsin) and Yellow-bellied Sapsuckers were more frequently observed on control segments.

#### HABITAT STRUCTURE ON TREATMENT AND CONTROL SEGMENTS

Habitat structure influences the composition of bird communities in many ways (see Cody 1985 for a recent review). Our sample design (long linear transects) was established to sample habitats in approximate proportion to their availability in the study areas in each state. Treatment and control



segments in Michigan and Wisconsin sample a wide range of habitats, including deciduous and coniferous woods, bogs, meadows, marshes, and logged areas of different ages. This diversity of habitats ensures that a diverse assemblage of birds will be sampled. The predominant influence of habitat structure on many aspects of bird communities means, however, that areas that differ in structure and species composition of the vegetation will differ (to a greater or lesser extent) in species composition and abundance of birds present.

Placement of treatment segments was constrained by the location of the ELF transmission lines. Thus, our sampling is not strictly random with respect to habitats in the study regions. In both states for example, treatment areas support more coniferous habitat, particularly lowland coniferous habitats, whereas control areas support more deciduous habitats (Blake et al. 1988). Differences in a variety of other habitat features also occur, but the deciduous-coniferous difference was most pronounced and, as has been discussed above, likely influenced composition of related bird communities. Several differences in bird community characteristics observed between treatment and control segments likely were due to differences in habitat and we are accounting for many of these differences with our analyses.

#### Habitat structure on Wisconsin segments

The experimental design in Michigan (before-and-after) will allow us to detect changes due to EM fields, apart from those due to habitat differences, if such changes occur. Because the antenna has been operating in Wisconsin since before this project started, we may not be able to detect effects of the EM fields without accounting for differences in habitat structure. We tried a different approach this year to account for such habitat effects; we paired treatment and control segments on the basis of vegetation. We reasoned that if habitat structure on treatment and control segments being compared was

similar, then differences in bird populations, if they occur, might be due to factors other than habitat.

Comparisons based on paired segments indicated that individuals were more abundant on control segments during July; no other comparisons revealed a significant difference between treatment and control segments for total species or individuals. Similarly, more significant differences were noted among abundant species; in most cases, correcting for habitat resulted in greater abundances on treatment segments. The Red-eyed Vireo serves as an appropriate example of this pattern (Fig. 3). This vireo prefers deciduous forest habitat and was slightly, but not significantly, more common on control segments when data from all segments were included (Fig. 3; see also Table 5). Deciduous trees account for 69% of all trees on control but only 43% of trees on treatment segments in Wisconsin (Blake et al. 1988). Mean abundance of Red-eyed Vireo was, however, significantly greater on treatment segments during May, June, and July, when comparisons were based on paired treatment and control segments (Fig. 3).

These analyses were done for 1988 only. The significance of observed patterns will be more apparent when results from other years are examined. Similarly, we will reexamine distribution patterns of different guilds (e.g., species preferring deciduous habitat). The apparent preference for treatment segments in Wisconsin has no immediately apparent explanation. Several of the species noted as more abundant on treatment segments after habitat differences were accounted for (e.g., Black-throated Green Warbler, Red-eyed Vireo) are forest birds and would not be attracted to potentially greater amount of edge habitat on treatment segments. Also, previous analyses have failed to demonstrate any apparent edge effect (Blake et al. 1988). More detailed, species-specific habitat analyses may provide some answers.

# RED-EYED VIREO WISCONSIN - 1988

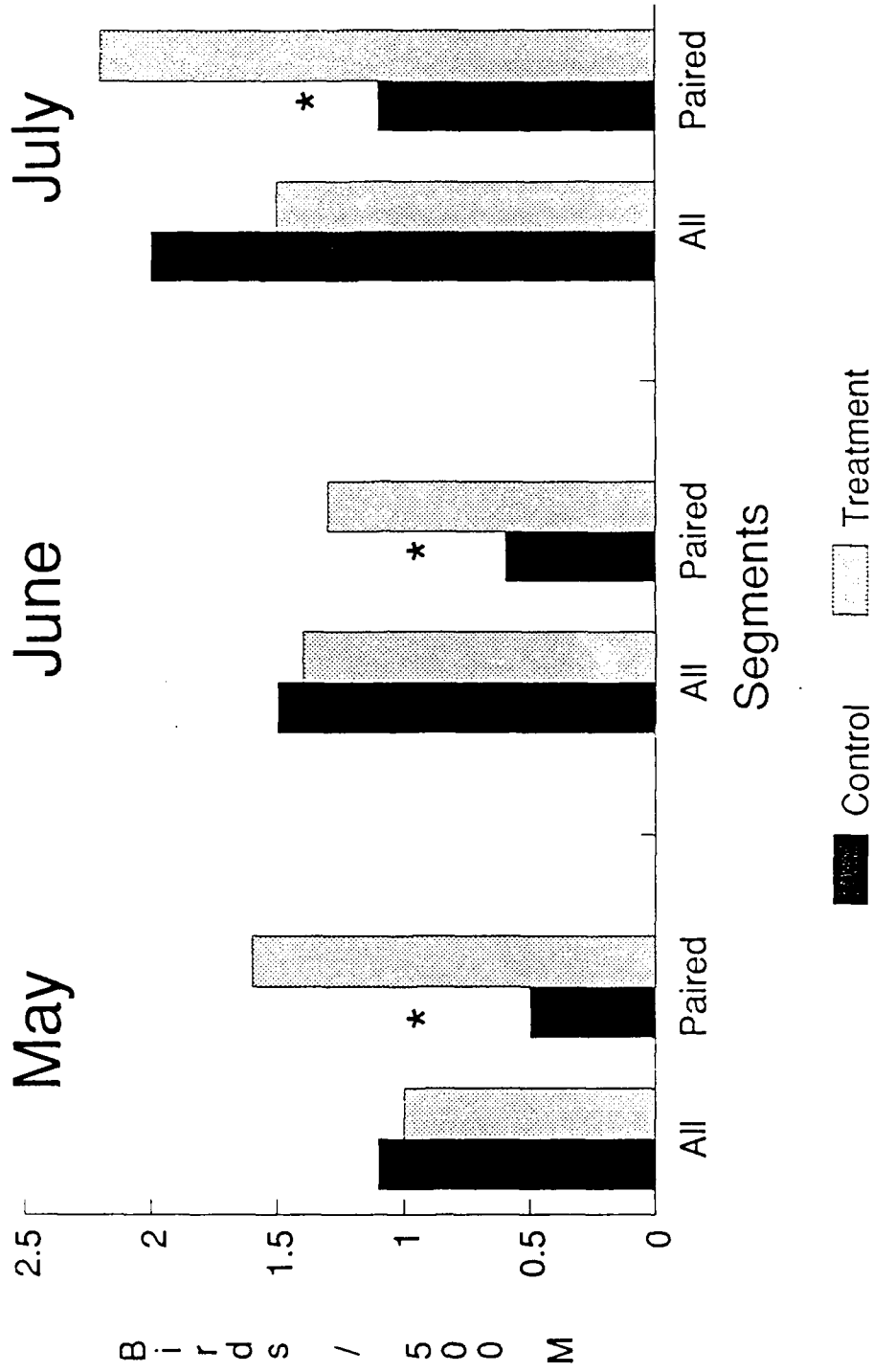


Figure 3. Red-eyed Vireos per 500 m on all segments and on paired treatment and control segments, Wisconsin 1988.

## OBJECTIVES

Our major objectives for 1988 were to complete bird censuses during all seasons in both states and to initiate analyses of the effects of habitat structure on bird distributions in Wisconsin. These objectives were met fully. Our objectives for 1989 and beyond are to continue our sampling of bird communities, following our established procedures. We also will be using the vegetation data from Wisconsin in more detailed analyses of bird - habitat relationships for that state. Such analyses will continue for the entire period that birds are sampled.

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Appendix 1. Summary of Experimental Design, Study Areas, and Methods used in the design and execution of research on effects of the ELF transmitter on bird communities and populations.

Appendix 1. Summary of Experimental Design, Study Areas, and Methods used in the design and execution of research on effects of the ELF transmitter on bird communities and populations.

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### EXPERIMENTAL DESIGN

The first steps in the experimental design were to (1) evaluate techniques for quantifying bird community parameters and (2) determine sample sizes required to detect a specified difference between control and treatment areas. Four potential techniques were examined: transect counts, point counts, territorial mapping, and mist-netting (Table A1). Territorial mapping and mist-netting were eliminated from consideration because of the amount of effort required to obtain statistically reliable results.

Transect and point counts are closely related techniques that differ primarily in a) whether the observer is moving (transects) or stationary (point counts) and b) in the size (area) of the experimental unit. For our comparison, we assumed that we could census an area 100 m from the point or transect line (both sides). The point count method would result in an effective census area of about 6.28 ha (assuming two point counts completed in the same time as one 500 m transect); a 500 m transect would cover about 10 ha. We decided to use transect counts because the ELF communications system consists of a long, linear network of the antenna and ROW and transects could be run parallel to this network. Point counts also could have been run adjacent to this network, but because we would walk along the swath adjacent to the ELF network, we decided to use the method that would include the larger census area (transects). In addition, if our estimates of the mean and variances are correct, transect counts are slightly more efficient in terms of effort (Table A1).

Table A1. Comparison of statistics for four bird census methods using the number of species as the community parameter of interest. Difference detectable was set at 15% of the mean and determination of sample size necessary to detect that difference was based on a probability of 0.05 and a power of 80% (Snedecor and Cochran 1967, p. 113). Formula used was:  $n = (15.8 \times S^2)/d^2$  where  $d$ =the absolute difference detectable or 15% of the mean (Snedecor and Cochran 1967). Statistics were estimated for forested habitats in the upper-midwestern United States based on the authors personal data.

Method	Mean number of species	Variance	Absolute difference detectable	N	Effort per n in hr	Initial effort per n in hr	Total effort in hr
Point count <sup>1</sup>	6.0	10.0	0.90	195	0.25	0.60	169
Transect count <sup>2</sup>	12.0	8.0	1.80	39	0.60	3.00	144
Territory mapping <sup>3</sup>	18.0	25.0	2.70	54	16.00	16.00	1728
Mist-netting <sup>4</sup>	1.6	1.8	0.24	494	0.50	0.25	371

<sup>1</sup> Estimates are for all species observed during 10 min count period.

<sup>2</sup> Estimates are for the number of species observed during a 30 min census of a 500 m transect.

<sup>3</sup> Estimates are for the total territorial males mapped in a 12.5 ha area.

<sup>4</sup> Estimates are for the number of species caught in a 12 m mist-net during a 5 hr period.

In an ideal experimental design, each segment should be randomly assigned to control and treatment areas. From the perspective of censusing in the field, however, this arrangement would be inefficient. To compromise statistical rigor with the practicalities of working in the field, we decided to group eight 500 m segments into one long transect line (hereafter called transect). Each segment was separated by a buffer of 50 m to reduce autocorrelation between the experimental units (Figure A1). We grouped eight segments because our previous experience indicated that bird censuses should be conducted from one half hour before sunrise to about four hours after sunrise. A total of 4 hours and 35 minutes are needed to census eight segments and seven buffers (30 minutes for each segment and 3 minutes for each buffer). We estimated that 39 segments (Table A1) were needed in each group (control and treatment for each state) to detect a 15% difference in number of species. This percent difference was selected based on the ability to detect a difference of one species between control and treatment areas. Therefore, we selected five transect starting points per group or a total of 160 segments (40 segments per group).

Placement of treatment transects with respect to the ELF antenna system was designed to achieve two goals: (1) to reduce or eliminate potential effects of the ROW edge on the bird community (Chasko and Gates 1982), and (2) to maintain an appropriate EM field within the treatment area. We placed the transects parallel to and 125 m from the edge of the ELF antenna ROW (Figure A1). This achieved a 25 m buffer from the limits of where we recorded birds (100 m) from the ROW edge. Although this placement reduced the intensity of EM fields within treatment areas, EM fields were still high enough to achieve the 10:1 ratio between treatment and control areas required in the study specifications (Brosh et al. 1986).

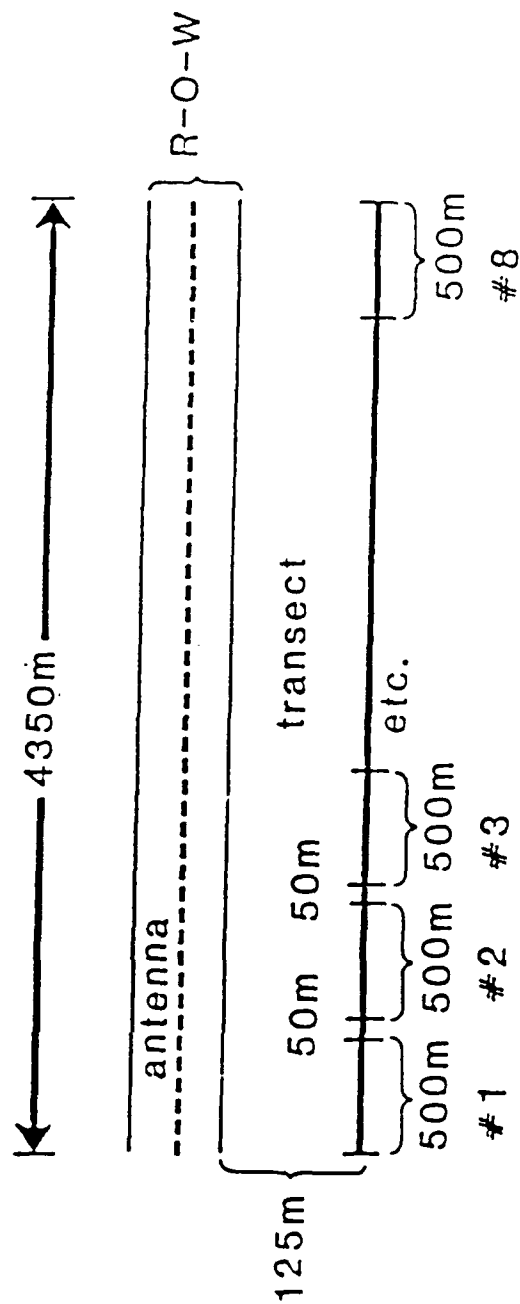


Figure A1. Schematic of a treatment transect layout. ROW = right-of-way.

### STUDY AREAS

Starting locations for 10 control and 10 treatment transects were randomly selected in Michigan and Wisconsin (Figures A2 and A3) with methods described previously (Niemi and Hanowski 1986). Electromagnetic fields were measured to insure that 76 Hz EM fields at a treatment site were significantly larger than: (1) 76 Hz EM fields at control sites, (2) 60 Hz fields at treatment sites, and (3) 60 Hz fields at control sites. In addition, exposure criteria required that there was no substantial difference in the ambient 60 Hz EM fields between control and treatment transects (Brosh et al. 1986). Electromagnetic fields were measured at the beginning and ending points for each transect; they were not completed for each transect segment because most were not easily reached (e.g., most are 1-4 km from a road). However, in 1988 EM fields were measured along one entire transect in Wisconsin and at various perpendicular distances from the antenna. These measurements will provide a measure of how EM fields vary both along and perpendicular to the antenna.

All transect pairs (control versus treatment) in Wisconsin fall within the "acceptable" category for EM field ratios established by IITRI. Eight of 25 transect pairs in Michigan were determined to be "conditionally acceptable" based on data collected in 1986. Previous data placed all pairs in the "acceptable" category (Haradem et al. 1987). All transects still satisfy the EM exposure criteria and will be used for the remainder of the monitoring period.

Information regarding proposed logging along the transects was obtained from Department of Natural Resources in Michigan and the U.S. Forest Service

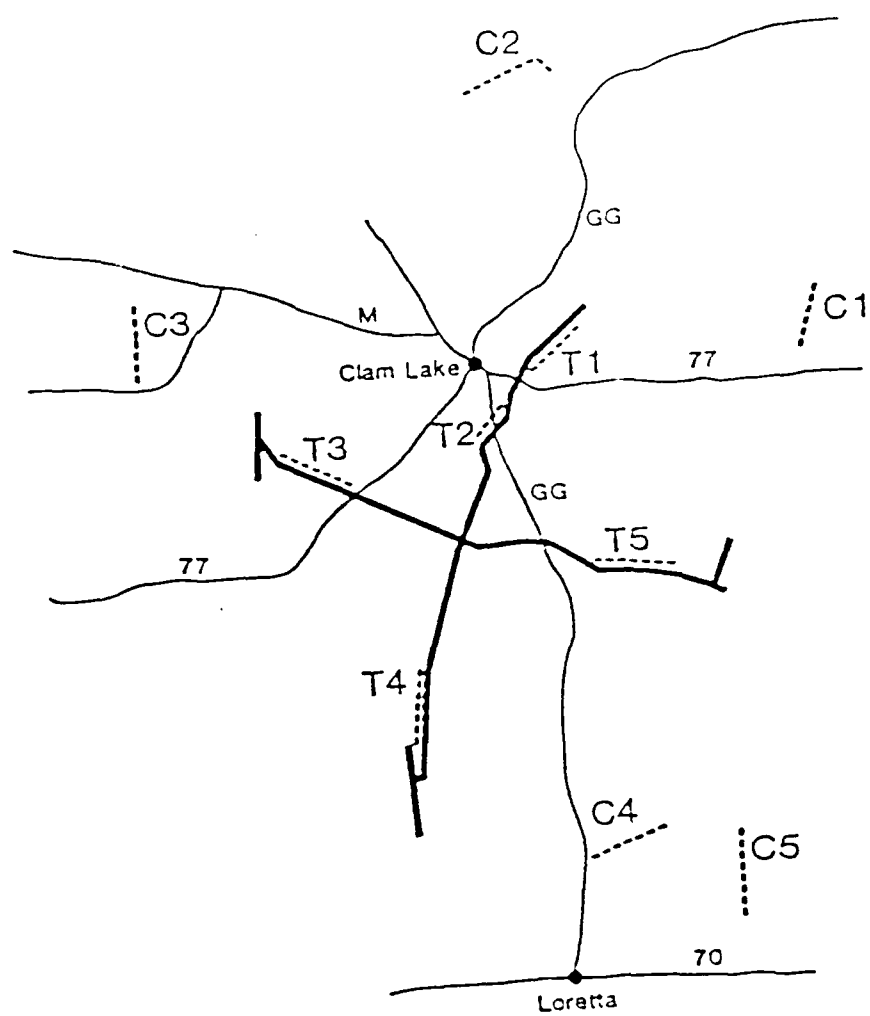


Figure A2. Location of Wisconsin antenna and study transects.



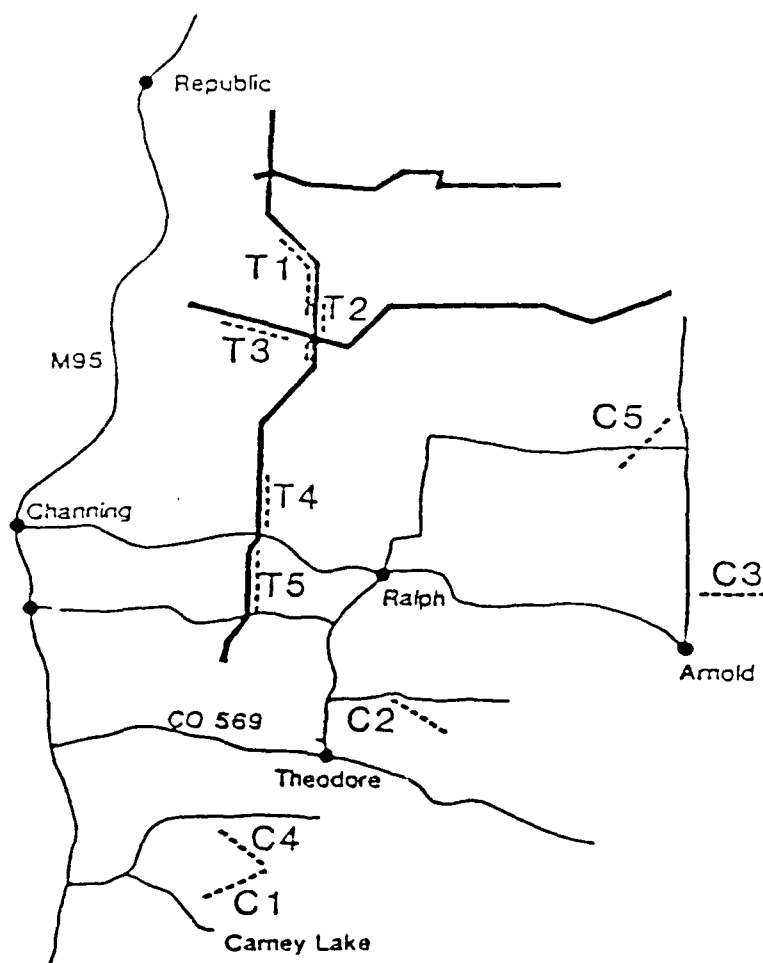


Figure A3. Location of Michigan antenna and study transects.

in Wisconsin. Five control and five treatment transect segments were scheduled for logging in Michigan effective through 1990 (Table A2). However, in an agreement reached with Michigan DNR (September 1988), logging on Carney Lake and Skunk Creek will not be completed until 1992 (Table A2). In Wisconsin, two control and eight treatment transect segments will be affected; however, all of these sites will be selectively cut or thinned (Table A2). Because of the length of our transects, it is probably impossible to avoid areas affected by logging. We will be sensitive to disturbances along transects in subsequent analyses and if necessary, affected transect segments can be removed from analyses. This will allow us to assess potential affect of logging or other disturbances on results of the investigation.

## METHODS

### Bird censuses

We used the line transect method to census all transects (Emlen 1971, 1977; Jarvinen and Vaisanen 1975). Census data were gathered during morning hours (one half hour to four and one half hours after sunrise) on days when wind speed was < 15 km/hr and when there was little or no precipitation. Control and treatment transect segments were censused simultaneously by two observers to eliminate differences that could occur by censusing at different times. Censuses of control and treatment transects were randomly assigned to each of two observers with the restriction that each observer census the same number of control (80) and treatment (80) segments in each census period. This was done to control for potential differences in observers.

Eight transect segments were censused daily by each observer. Each observer walked the designated transect segment at a rate of 16.7 m/min and recorded the following for each bird observed: (1) species; (2) sex when

Table A2. Summary of Michigan and Wisconsin transect locations and proposed logging of study areas effective through 1990. Asterisks denote sections that were logged in 1987 (\*) and 1988 (\*\*). No additional study areas in Michigan will be logged before the end of the study.

Number and Name	Township	Range	Sections	Number of 500 m segments affected
<b>MICHIGAN</b>				
C1 Carney Lake	41N	29W	33,34,35,36	2 (1992)
C2 Skunk Creek	42N	28W	14,23,24	2 (1992)
	42N	27W	19,30	
C3 Arnold	43N	25W	31,32,33,34	1 *
C4 Lost Lake	41N	29W	21,26,27,28,35	2 **
C5 Bob's Creek	44N	26W	13,23,24,26	1 (1989)
T1 Heart Lake	45N	28W	7,18	1
	46N	29W	1	
T2 Flat Rock Creek	44N	28W	6	3 *
	45N	28W	19,30,31	
T3 Schwartz Creek	45N	28W	31	2 **
	45N	29W	26,27,35,36	
T4 Turner Road	43N	29W	1,11,12	0
	44N	29W	36	
T5 Leeman's Road	43N	29W	14,23,26,35	0
<b>WISCONSIN</b>				
C1 Spillerberg Lake	43N	3W	23,26,35	0
C2 Mineral Lake	44N	4W	15,16,17,18	0
C3 Rock Lake	42N	6W	6	1 (thinning)
	43N	6W	19,30,31	
C4 Blaisdell Lake	40N	4W	13,14,22,23	0
	40N	3W	18	
C5 Brunette River	40N	3W	16,21,28	1 (thinning)

Table A2 continued

Number and Name	Township	Range	Sections	Number of 500 m segments affected
T1 Woodtick Lake	43N	4W	22,23,27,28,33	0
T2 Little Clam Lake	42N	4W	5,8,17	3 (thinning)
T3 Christy Lake	42N	5W	7,8,15,16,17	1 (thin part) * 1 (thin all) *
T4 Black Lake	41N	5W	24,25,36	0
T5 Moose River	42N	3W	31	1 (thin part) *
	42N	4W	35,36	2 (thin all) *

possible; (3) behavior (e.g., singing or calling); (4) estimated perpendicular distance from the segment center line, in meters; (4) position relative to the segment center line (e.g., right or left side); and (5) distance, in meters, from the start of the segment. Information for each individual bird observed was recorded on microcomputer files directly from field sheets. Birds flying over (i.e., above the canopy) were not included. Data were checked for accuracy by someone other than the original data entry person.

We used the number of individual's observed up to 100 m from the segment center line in all data analyses instead of attempting to calculate a density value. Relative density could be calculated with a variety of formulae (Emlen 1971, 1977; Jarvinen and Vaisanen 1975; Burnham et al. 1981) but at the present we have no basis for using one formula over another. We only assume that the number of birds recorded is related to the density of birds in an area. A disadvantage to using a density formula (e.g., LINETRAN; Burnham et al. 1981) is the number of observations required to obtain a reliable density estimate. For example, at least 30 observations/species are recommended to calculate densities with the Fourier series estimator. Such a sample size is prohibitive for this study because we do not observe this many individuals of one species on a 500 m segment. To obtain the specified sample, our segments would have to be about five times longer (about 2500 m) than they are now. This design is not feasible because of the large sample size (number of segments) needed to detect the desired difference between control and treatment areas. It may be possible to use this technique at a later date if we pool data among years or among different experimental units.

An advantage of using total number of observations is that we reduce potential variability between observers in ability to estimate distance

(Svensson 1977). Here we only assume that the ability to detect individuals is similar between observers and, therefore, between control and treatment sites because each observer censuses the same number of control and treatment segments.

### Bird guilds

We listed all bird species observed in Michigan and Wisconsin and all species that could potentially occur in our study areas. Each species was classified by 1) nesting area, 2) food or foraging type, 3) breeding habitat preference, and 4) migration type (Appendix 2). Classifications were based on published sources (e.g., Martin et. al. 1951; Bent 1963, 1964; Green and Niemi 1978; Terres 1982; AOU 1983, 1985) and personal observations. A hierarchical classification scheme was used if a species occurred in more than one category. When this occurred, we identified primary, secondary, and tertiary areas of use for these species; primary being the predominant category of use. We use this information in analyses to address any differential effects of the ELF antenna on species that use particular feeding strategies, specific nesting areas, or different migration patterns (see Verner 1984). These analyses allow us to test for differences between control and treatment transects for species that have similar life history characteristics and therefore, similar exposures to ELF EM fields.

### Wisconsin vegetation

Vegetation on all 80 control and treatment segments was measured over a two year period (1986 and 1987). A two year period was selected to more efficiently use personnel and to better control for seasonal variation in vegetation growth. A representative portion of segments measured in 1986 were

remeasured in 1987 to quantify annual differences in vegetation growth and/or variation in sampling efficiency.

Vegetation samples were collected at 25 m intervals to describe changes that occur within each segment. Sample points were positioned two meters from the transect line to avoid biases in where flag markers for transects were placed. We used methods that we have successfully used in past investigations to assess habitat characteristics (Niemi and Hanowski 1984; Niemi 1985); methods were modified from Wiens (1969) and Wiens and Rotenberry (1981). Densities of trees, shrubs, forbs, and graminoids were calculated with the point-centered quarter method (Cottam and Curtis 1956). Vegetation variables measured and their description are in Appendix 3A. All vegetation data were entered onto microcomputer files and checked for accuracy by someone other than the original data entry person.

#### Michigan vegetation

We classified habitats of the Michigan study areas at 25 m intervals along each segment. Nineteen habitat types were used for classification (Appendix 4) and percentage of occurrence of each type on control and treatment areas was calculated. We did this to identify gross habitat differences between control and treatment segments that might potentially explain differences in bird populations. For example, before the antenna is turned on in Michigan we would expect that any differences between control and treatment transects would be due to some other source of difference between these areas (i.e., habitat). We collected 1750 vegetation samples in Michigan and entered these data onto microcomputer files. A goodness-of-fit G-test was used to test for differences between control and treatment transects using the frequencies of the 19 habitat types observed.

Appendix 2. Nesting, feeding, habitat, and migration classifications for bird species observed in Michigan and Wisconsin.



Appendix 2. Nesting, feeding, habitat, and migration classification for bird species observed in Michigan and Wisconsin.

Species	Nesting	Food	Habitat	Migration
Common Loon	1	1	9,8	2
Pied-billed Grebe	1	1	9,8	2
American Bittern	3	1	6,9	2
Great Blue Heron	2	1	9,1,2,3	2
Wood Duck	4	18	9,1	2
Mallard	1	18	9,8	2
Blue-winged Teal	1	18	9,8	3,2
Turkey Vulture	1	3	3,1,5	2,3
Osprey	2	1	9,3	2,3
Bald Eagle	2	1	9,3	2,1
Northern Harrier	1	2	8,5,10	2,3
Sharp-shinned Hawk	2	2	2,3,11	2
Cooper's Hawk	2	2	1,3	2
Northern Goshawk	2	2	2,3	4,1
Broad-winged Hawk	2	2	3,1	3
Red-tailed Hawk	2	2	5,1	2
American Kestrel	4	2	5,4	2,3
Spruce Grouse	1	4	2,11	1
Ruffed Grouse	1	4	1,3,4	1
Virginia Rail	3	19	6,8	2
Sora	3	19,18	8,6	2
Sandhill Crane	1	5	8,5,10	2
Solitary Sandpiper	2,3	19	9	3

## Appendix 2 (continued)

Species	Nesting	Food	Habitat	Migration
Spotted Sandpiper	1	19	9	2,3
Common Snipe	1	19	8,6,5	2
American Woodcock	1	6	6,5,4,1	2
Mourning Dove	2,3	7	5,7	2
Black-billed Cuckoo	3	10	1,4,6	3
Yellow-billed Cuckoo	3	10	1,4,6	3
Great Horned Owl	2	2	3,2,1	1
Barred Owl	2	2	1,3	1
Common Nighthawk	1	11	3,7,4	3
Whip-poor-will	1	11	1,3,4	2
Chimney Swift	4	11	7,3,1	3
Ruby-throated Hummingbird	2	17	5,7,4	3
Belted Kingfisher	4	1	9	2
Yellow-bellied Sapsucker	4	17,16	1,3,2	2
Downy Woodpecker	4	16	1,4,3	1
Hairy Woodpecker	4	16	1,3,4	1
Black-backed Woodpecker	4	16	2,11,3	1
Northern Flicker	4	9	1,3,2	2
Pileated Woodpecker	4	16	1,3,2	1
Olive-sided Flycatcher	2	12	4,11,2	3
Eastern Wood-Pewee	2	12	3,1,2	3
Yellow-bellied Flycatcher	1	12	11,2	3
Alder Flycatcher	3	12	6	3
Least Flycatcher	2	12	1,3,4	3

## Appendix 2 (continued)

Species	Nesting	Food	Habitat	Migration
Eastern Phoebe	5	12	9,7	2
Great Crested Flycatcher	4	12	1,3	3
Eastern Kingbird	2,3	12	5,4,10,8	3
Tree Swallow	4	11	5,7,4,9	2,3
Gray Jay	2	5	11,3,2	1
Blue Jay	2	5	1,3,2	1
American Crow	2	5	5,1,3,7	2,1
Common Raven	2	5	2,3,7	1
Black-capped Chickadee	4	10	1,3,11,2	1
Boreal Chickadee	4	10	11,2	1
Red-breasted Nuthatch	4	16	2,3,11,1	1
White-breasted Nuthatch	4	16	1,3	1
Brown Creeper	4	16	1,3,2,11	2,1
House Wren	4	10	7,4	2
Winter Wren	1,6	10	3,11,4,2	2
Sedge Wren	3	10	8,6,5	2
Marsh Wren	3	10	8	2
Golden-crowned Kinglet	2	10	2,11	2,1
Ruby-crowned Kinglet	2	10	2,11,4,6	2
Veery	1	9	1,4,3,6	3
Gray-cheeked Thrush	3	9	4,11,2	3
Swainson's Thrush	2,3	9	11,2,4	3
Hermit Thrush	1	9	3,11,1,2	2
Wood Thrush	3,1	9	1,3	3

## Appendix 2 (continued)

Species	Nesting	Food	Habitat	Migration
American Robin	2,3,1	9	5,7,4,1	2,1
Gray Catbird	3	13	4,6,7	2,3
Brown Thrasher	3	9	4,7	2
Bohemian Waxwing	2	14	4,3,1	4
Cedar Waxwing	2	14	4,3,1	1,2
European Starling	4	9	7,3	1
Solitary Vireo	2	10	3,11,2	3,2
Yellow-throated Vireo	2	10	1,3	3
Warbling Vireo	2	10	4,3,1	3
Philadelphia Vireo	2,3	10	1,3,6	3
Red-eyed Vireo	2,3	10	1,3,4	3
Golden-winged Warbler	1,3	10	4,6	3
Tennessee Warbler	1	10	3,2,6,4	3
Orange-crowned Warbler	1	10	6,4,3	2,3
Nashville Warbler	1	10	3,4,11,2	3
Northern Parula	2	10	11,3,2	3
Yellow Warbler	3	10	6,5,7	3
Chestnut-sided Warbler	3	10	4,3	3
Magnolia Warbler	2,3	10	4,2,3	3
Cape May Warbler	2	10	2,3	3
Black-throated Blue Warbler	3	10	1,3,4	3
Yellow-rumped Warbler	2	13	2,3,11,4	2,3
Black-throated Green Warbler	2	10	3,1	3

## Appendix 2 (continued)

Species	nesting	Food	Habitat	Migration
Blackburnian Warbler	2	10	2,3	3
Pine Warbler	2	10	2	2
Palm Warbler	1	6	11,10	2,3
Bay-breasted Warbler	2	10	2,3	3
Blackpoll Warbler	2	10	2,4,3	3
Black-and-white Warbler	1	16	3,4,6,1	3
American Redstart	2,3	12,10	4,1,6	3
Ovenbird	1	6	1,3,2,4	3
Northern Waterthrush	1,6	6	9	3
Connecticut Warbler	1	10	11	3
Mourning Warbler	1,3	10	4,3	3
Common Yellowthroat	3	10	6,8,4	2,3
Wilson's Warbler	3	10	6	3
Canada Warbler	3	10	3,4	3
Scarlet Tanager	3	10	1,3	3
Rose-breasted Grosbeak	3,2	13	1,4,3	3
Indigo Bunting	3	15	5,4	3
Rufous-sided Towhee	1,2,3	8	4	2
American Tree Sparrow	3	7	5	4,2
Chipping Sparrow	2	8	2,3,4,11	2
Clay-colored Sparrow	3	8	5,6	2,3
Field Sparrow	1,3	8	5	2
Savannah Sparrow	1	8	5,8,10	2
Fox Sparrow	1,3	8	4,5	2

## Appendix 2 (continued)

Species	Nesting	Food	Habitat	Migration
Song Sparrow	3	8	5,4,6	2
Lincoln's Sparrow	1	8	10,8,4	2
Swamp Sparrow	3	8	6,8	2
White-throated Sparrow	1	8	4,3,2,11,1	2
White-crowned Sparrow	1,3	8	4,6,5	2
Dark-eyed Junco	1	8	11,2,3,4	2,1
Snow Bunting	5	7	5	4
Bobolink	1	8	5,8	3
Red-winged Blackbird	3	8	8	2
Eastern Meadowlark	1	6	5	2
Western Meadowlark	1	6	5	2
Yellow-headed Blackbird	3	8	8	2
Rusty Blackbird	3	8	9	2
Brewer's Blackbird	3,1	8	5	2
Common Grackle	3	5	5,9,7	2
Brown-headed Cowbird	7	8	5,4,1,7	2
Northern Oriole	2	13	1,3	3
Pine Grosbeak	2	7	2,11	4
Purple Finch	2	7	3,2,4	2,1
Red Crossbill	2	7	2,11,3	4,1
White-winged Crossbill	2	7	2,11,3	4,1
Common Redpoll	3	7	5	4
Hoary Redpoll	3	7	5	4
Pine Siskin	2	15	2,3	1,4

## Appendix 2 (continued)

Species	Nesting	Food	Habitat	Migration
American Goldfinch	3,2	7	5,6,4	2
Evening Grosbeak	2	15	3,2,7	1,4
House Sparrow	4	7	7	1

## A. Nesting

- 1 Ground
- 2 Canopy or canopy vegetation (tree but not necessarily tree top)
- 3 Subcanopy or shrub
- 4 Cavity, hole or bank
- 5 Ledge or platform
- 6 Cavity - tree roots
- 7 Nest parasite

## B. Food

- 1 Aquatic vertebrates, including species feeding on fish or other aquatic vertebrates
- 2 Predator on birds, small mammals, large insects
- 3 Scavenger
- 4 Species feeding on vegetation such as buds, pine needles, and seeds but excluding species concentrating on seeds or fruits
- 5 Omnivores; various small vertebrates (including eggs and young), invertebrates, plants, carrion, etc.
- 6 Ground invertebrates
- 7 Seeds (plus a smaller amount of fruit by some species)
- 8 Ground insects and seeds

## Appendix 2 (continued)

- 9 Ground insects and fruit
- 10 Foliage insects
- 11 Aerial insects - taken while in continuous flight
- 12 Flycatchers
- 13 Foliage insects and fruit
- 14 Fruit
- 15 Foliage insects and seeds
- 16 Bark insects
- 17 Nectar and sap
- 18 Aquatic vegetation
- 19 Aquatic invertebrates

## C. Habitat

- 1 Deciduous forest
- 2 Coniferous forest
- 3 Mixed deciduous - coniferous forest
- 4 Early successional deciduous - coniferous forest
- 5 Fields and meadows
- 6 Shrub swamp
- 7 Urban
- 8 Open wetlands (e.g., sedge fen, cattail)
- 9 Ponds, lakes, rivers, and streams
- 10 Muskeg
- 11 Lowland coniferous forest



## Appendix 2 (continued)

## D. Migration

- 1 Permanent resident; populations may be augmented during winter or during summer
- 2 Short-distance migrant; generally includes breeders; individuals generally winter south of study areas but most winter north of the tropics
- 3 Long-distance migrant; generally winter south of the U.S.
- 4 Winter resident

Appendix 3A. Description of habitat variables used to quantify habitat characteristics of Wisconsin study areas.

Appendix 3A. Description of habitat variables used to quantify habitat characteristics of Wisconsin study areas.

Habitat Variable	Description
Ground Cover	Estimate of percent of green vegetation less than 10 cm in m <sup>2</sup> surrounding the center point
Water Cover	Estimate of percent of standing water in m <sup>2</sup> surrounding the center point
Water Depth	Depth at center point
Overall Height	Estimate of the average height of vegetation in 25 m <sup>2</sup> surrounding center point
Tree Density	Density of trees greater than 2.5 cm diameter breast height (dbh) measured by the point-centered method
Tree Height	Height of four trees measured for tree density; measured with a clinometer
Tree Species	Identification of four trees measured for tree density
Tree Diameter	Measured dbh of four trees measured for tree density
Canopy Cover	Average of four readings taken with a spherical densiometer in NE quarter of point-centered plot
Log Density	Density of fallen logs greater than 2.5 cm diameter measured by the point-centered quarter method
Log Species	Identification of four logs measured for log density
Log Diameter	Measured diameter of four logs measured for log density. Diameter was measured at point where log was closest to center point.
Shrub Density	Density of shrubs greater than 30 cm and less than 2.5 cm dbh measured by the point-centered method. Shrubs were defined as any plant species that was persistent in the environment year round at a height of at least 30 cm (e.g., woody shrubs and cattails)
Shrub Height	Height of four shrubs measured for shrub density
Shrub Species	Species of four shrubs measured for shrub density
Forb Density	Density of forbs > 10 cm high measured by the point-centered method

## Appendix 3A (continued)

Habitat Variable	Description
Forb Species	Species of four forbs measured for forb density
Grass-Sedge Density	Density of grasses and sedges > 10 cm high measured by the point-centered method

Appendix 3B. Proportion of variation explained and important variables (in order of importance) for seven factors calculated with principal components analysis of vegetation data from Wisconsin. Weighted factor scores were used to pair control and treatment transects (see text for detail).

Appendix 3B. Proportion of variation explained and important variables (in order of importance) for seven factors calculated with principal components analysis of vegetation data from Wisconsin. Weighted factor scores for each transect segment were used to pair control and treatment transects (see text for detail).

Factor	Proportion of Variation	Important Variables
1	.2588	Tree Height, overall height, deciduous basal area, sugar maple importance value
2	.1262	Black ash importance value, water cover, cedar importance value
3	.1065	Coniferous basal area, tree density
4	.0707	Number of shrub species, number of tree species
5	.0673	Balsam importance value, density of trees 15-23 cm dbh, coniferous basal area
6	.0570	Density of trees 15-23 cm dbh
7	.0489	Shrub density

Appendix 4. Description of habitat types used to classify Michigan study areas.

Appendix 4. Description of habitat types used to classify Michigan study areas.

Habitat Type	Description
Upland Conifer Forest	Upland forest with > 90% conifer species (e.g., pine)
Lowland Conifer Forest	Lowland forest with > 90% conifer species (e.g., black spruce)
Upland Deciduous Forest	Upland forest with > 90% mixed deciduous species
Maple Forest	Upland deciduous forest with > 90% maple sp.
Lowland Deciduous Forest	Lowland forest with > 90% deciduous species (e.g., black ash)
Upland Mixed Forest	Upland forest with mixed deciduous and coniferous species
Lowland Mixed Forest	Lowland forest with mixed deciduous and coniferous species
Cedar Forest	Lowland forest with > 90% cedar
Wet Shrub	Alder/willow wetland with no or few trees
Tree Shrub	Alder/willow wetland with trees (e.g., black ash or tamarack)
New Cut	Logged area < 5 years old
Young Cut Aspen	Logged area with aspen < 3m
Young Cut Mixed	Logged area with mixed species < 3m
Short Aspen	Logged area with aspen > 3m but < 10m
Short Mixed	Logged area with mixed species > 3m but < 10m
Open	Forest opening
Sedge	Wet sedge meadow
Pond	Small pond
Cattail	Wet area with > 90% cattail



Appendix 5A. Total number of individuals and species observed on control (C) and treatment (T) transects in Michigan during five census periods in 1987. English and scientific names follow AOU (1983, 1985).

Appendix 5a. Total number of individuals and species observed on control (C) and treatment (T) transects in Michigan during five census periods in 1988. English and scientific names follow AOU(1983,1985).

	May		June		July		August		September	
	T	C	T	C	T	C	T	C	T	C
Pied-billed Grebe <u>Podilymbus podiceps</u>					0	2				
American Bittern <u>Botaurus lentiginosus</u>	1	1								
Least Bittern <u>Ixobrychus exilis</u>					1	0				
Great Blue Heron <u>Ardea herodias</u>							0	1		
Canada Goose <u>Branta canadensis</u>	0	2								
Wood Duck <u>Aix sponsa</u>	0	1					0	2		
Mallard <u>Anas platyrhynchos</u>	0	1	0	2						
Blue-winged Teal <u>Anas discors</u>			1	0						
Hooded Merganser <u>Lophodytes cucullatus</u>	0	2								
Turkey Vulture <u>Cathartes aura</u>	2	0								
Northern Harrier <u>Circus cyaneus</u>					1	0				
Sharp-shinned Hawk <u>Accipiter striatus</u>	1	0	0	1			2	0		
Cooper's Hawk <u>Accipiter cooperii</u>			1	0						
Northern Goshawk <u>Accipiter gentilis</u>			1	0						
Broad-winged Hawk <u>Buteo platyterus</u>	3	1	1	0	0	1	2	2	2	0

Table 5a (Continued)

	May		June		July		August		September	
	T	C	T	C	T	C	T	C	T	C
Red-tailed Hawk <u>Buteo jamaicensis</u>	0	2	0	1	0	1	0	1	1	0
American Kestrel <u>Falco sparverius</u>							5	0		
Ruffed Grouse <u>Bonasa umbellus</u>	16	17	5	4	2	23	12	5	5	8
Sora <u>Porzana carolina</u>			0	1	0	1				
Sandhill Crane <u>Grus canadensis</u>							0	2		
Killdeer <u>Charadrius vociferus</u>					1	0				
Common Snipe <u>Gallinago gallinago</u>	1	4			0	2				
American Woodcock <u>Scolopax minor</u>	0	1	1	4	4	1	5	0	8	1
Mourning Dove <u>Zenaidura macroura</u>	0	1	0	2						
Black-billed Cuckoo <u>Coccyzus erythrophthalmus</u>			0	2	2	1				
Barred Owl <u>Strix varia</u>			0	1						
Common Nighthawk <u>Chordeiles minor</u>					0	1			0	3
Whip-poor-will <u>Caprimulgus vociferus</u>			1	0					1	0
Belted Kingfisher <u>Ceryle alcyon</u>	0	1	0	2			1	4		
Yellow-bellied Sapsucker <u>Sphyrapicus varius</u>	21	55	9	17	7	25	5	12	4	13

Table 5a (Continued)

	May		June		July		August		September	
	T	C	T	C	T	C	T	C	T	C
Downy Woodpecker <u>Picoides pubescens</u>	10	8	1	2	5	9	2	0	0	1
Hairy Woodpecker <u>Picoides villosus</u>	3	1	1	3	1	5	9	6	11	5
Black-backed Woodpecker <u>Picoides arcticus</u>					1	0	1	0	1	2
Northern Flicker <u>Colaptes auratus</u>	24	28	12	4	15	11	9	6	9	18
Pileated Woodpecker <u>Dryocopus pileatus</u>	1	0	0	1			0	4	2	6
Olive-sided flycatcher <u>Contopus borealis</u>			0	1	1	0	2	0		
Eastern Wood-Pewee <u>Contopus virens</u>			8	10	3	5	14	15	5	7
Yellow-bellied Flycatcher <u>Empidonax flaviventris</u>	1	1	19	10	10	5	3	2	0	1
Alder Flycatcher <u>Empidonax alnorum</u>			13	11	3	3	0	1		
Least Flycatcher <u>Empidonax minimus</u>	13	14	25	50	23	25	1	1		
Eastern Phoebe <u>Sayornis phoebe</u>					1	0	0	1	1	0
Great Crested Flycatcher <u>Myiarchus crinitus</u>	1	7	10	20	5	7	1	2	1	0
Eastern Kingbird <u>Tyrannus tyrannus</u>			5	1	2	2	0	2	0	1
Tree Swallow <u>Iachycineta bicolor</u>	2	15			0	2				
Gray Jay <u>Perisoreus canadensis</u>	3	2	0	1	1	2	5	1	1	6

Table 5a (Continued)

	May		June		July		August		September	
	T	C	T	C	T	C	T	C	T	C
Blue Jay <u>Cyanocitta cristata</u>	21	40	18	27	22	24	18	22	31	37
American Crow <u>Corvus brachyrhynchos</u>	2	1	2	2	4	1	0	1	2	0
Common Raven <u>Corvus corax</u> Linnaeus	10	5	1	0	1	2	0	2	0	4
Black-capped Chickadee <u>Parus atricapillus</u>	56	66	23	20	27	65	81	84	76	102
Boreal Chickadee <u>Parus hudsonicus</u>	2	0	2	0	2	0	2	2	3	0
Red-breasted Nuthatch <u>Sitta canadensis</u>	23	29	2	2			36	41	20	39
White-breasted Nuthatch <u>Sitta carolinensis</u>	5	14	0	3			1	2	4	4
Brown Creeper <u>Certhia americana</u>	1	15	4	10	5	20	10	16	29	24
House Wren <u>Troglodytes aedon</u>			2	0	2	0				
Winter Wren <u>Troglodytes troglodytes</u>	31	42	9	28	15	25	8	6	2	3
Sedge Wren <u>Cistothorus platensis</u>			8	3	2	5	3	0	0	7
Marsh Wren <u>Cistothorus palustris</u>			4	3						
Golden-crowned Kinglet <u>Regulus satrapa</u>	61	67	41	30	57	27	83	42	33	40
Ruby-crowned Kinglet <u>Regulus calendula</u>	23	9	6	1	5	0			1	2
Eastern Bluebird <u>Sialia sialis</u>			1	0	4	1				

Table 5a (Continued)

	May		June		July		August		September	
	T	C	T	C	T	C	T	C	T	C
Veery <u>Catharus fuscescens</u>			14	14	19	19	3	1		
Swainson's Thrush <u>Catharus ustulatus</u>	10	0	11	16	23	34			0	2
Hermit thrush <u>Catharus guttatus</u>	43	38	36	32	52	50	25	18	11	16
Wood Thrush <u>Hylocichla mustelina</u>			3	8	0	2	0	1		
American Robin <u>Turdus migratorius</u>	48	49	27	21	31	7	19	6	6	11
Gray Catbird <u>Dumetella carolinensis</u>			1	0	1	0			1	1
Brown Thrasher <u>Toxostoma rufum</u>			3	0	3	0				
Cedar Waxwing <u>Bombycilla cedrorum</u>			9	5	20	17	36	5	38	15
European Starling <u>Sturnus vulgaris</u>	3	4								
Solitary Vireo <u>Vireo solitarius</u>	6	2	3	4	5	2			1	0
Yellow-throated Vireo <u>Vireo flavifrons</u>					1	1	0	1	2	1
Philadelphia Vireo <u>Vireo philadelphicus</u>					1	0				
Red-eyed Vireo <u>Vireo olivaceus</u>	0	1	58	76	56	53	11	15	0	1
Golden-winged Warbler <u>Vermivora chrysoptera</u>			19	8	0	1			0	1
Tennessee Warbler <u>Vermivora peregrina</u>	0	2	5	1						

Table 5a (Continued)

	May		June		July		August		September	
	T	C	T	C	T	C	T	C	T	C
Nashville Warbler <u>Vermivora ruficapilla</u>	58	74	110	72	58	46	4	6	2	11
Northern Parula <u>Parula americana</u>			6	11	2	16				
Yellow Warbler <u>Dendroica petechia</u>	1	0	0	1	1	1	0	1		
Chestnut-sided Warbler <u>Dendroica pensylvanica</u>			66	22	42	16	0	3	3	8
Magnolia Warbler <u>Dendroica magnolia</u>			0	2	1	0	1	0	1	6
Cape May Warbler <u>Dendroica tigrina</u>			1	1						
Black-throated Blue Warbler <u>Dendroica caerulescens</u>			0	1						
Yellow-rumped Warbler <u>Dendroica coronata</u>	67	42	25	14	14	9	4	0	13	4
Black-throated Green Warbler <u>Dendroica virens</u>	15	39	43	44	30	39	9	7	4	3
Blackburnian Warbler <u>Dendroica fusca</u>			5	16	1	3				
Pine Warbler <u>Dendroica pinus</u>					2	1				
Palm Warbler <u>Dendroica palmarum</u>							1	0		
Bay-breasted Warbler <u>Dendroica castanea</u>									0	3
Black-and-white Warbler <u>Mniotilta varia</u>	3	15	17	28	8	15	2	5	2	8
American Redstart <u>Setophaga ruticilla</u>			2	2	0	1			2	5

Table 5a (Continued)

	May		June		July		August		September	
	T	C	T	C	T	C	T	C	T	C
Ovenbird <u>Seiurus aurocapillus</u>	1	14	123	136	79	93	13	19	8	20
Northern Waterthrush <u>Seiurus noveboracensis</u>					0	2	0	2		
Connecticut Warbler <u>Oporornis agilis</u>	0	1	2	2	3	0	3	0		
Mourning Warbler <u>Oporornis philadelphia</u>	1	0	17	6	17	15	1	0		
Common Yellowthroat <u>Geothlypis trichas</u>			15	17	3	17	2	7	4	0
Canada Warbler <u>Wilsonia canadensis</u>	1	0	0	1						
Scarlet Tanager <u>Piranga olivacea</u>			1	7	2	7	0	2		
Rose-breasted Grosbeak <u>Pheucticus ludovicianus</u>	1	1	34	41	17	8	2	1	0	4
Indigo Bunting <u>Passerina cyanea</u>			5	7	12	14	1	0	1	0
Rufous-sided Towhee <u>Pipilo erythrophthalmus</u>	0	1	5	4	7	4	1	0	3	0
Chipping Sparrow <u>Spizella passerina</u>	24	17	25	8	19	10	2	1		
Clay-colored Sparrow <u>Spizella pallida</u>	0	1	0	1						
Le Conte's Sparrow <u>Ammodramus leconteii</u>	1	0								
Song Sparrow <u>Melospiza melodia</u>	23	6	14	3	9	13	6	0	3	4
Swamp Sparrow <u>Melospiza georgiana</u>	10	19	3	6	7	12	1	7	2	6



Table 5a (Continued)

	May		June		July		August		September	
	T	C	T	C	T	C	T	C	T	C
White-throated Sparrow <u>Zonotrichia albicollis</u>	91	57	75	37	68	22	17	9	33	15
Dark-eyed Junco <u>Junco hyemalis</u>	6	0	4	0	12	0			3	0
Red-winged blackbird <u>Agelaius phoeniceus</u>	4	30	3	11	0	14			0	1
Common Grackle <u>Quiscalus quiscula</u>	5	8	1	7	1	5	1	1		
Brown-headed Cowbird <u>Molothrus ater</u>	4	11	1	10	0	2				
Northern Oriole <u>Icterus galbula</u>			0	3						
Purple Finch <u>Carpodacus purpureus</u>	9	15	0	1	0	4			3	0
Pine Siskin <u>Carduelis pinus</u>	4	7								
American Goldfinch <u>Carduelis tristis</u>			3	1	1	2	5	6	0	1
Evening Grosbeak <u>Coccothraustes vespertinus</u>	6	2	5	3	1	1			0	4
Unidentified passerine	21	20	21	13	21	19	69	51	67	80
Unidentified woodpecker	11	9	3	10	6	6	4	6	3	4
Unidentified non-passerine	0	1								
Total individuals	815	939	1061	1014	891	907	564	469	469	574
Total species*	53	56	70	77	69	68	50	51	46	47

\* Does not include unidentified birds.

Appendix 5B. Total number of individuals and species observed on control (C) and treatment (T) transects in Wisconsin during five census periods in 1987. English and scientific names follow AOU (1983, 1985).

Appendix 5b. Total number of individuals and species observed on control (C) and treatment (T) transects in Wisconsin during five census periods in 1988. English and scientific names follow AOU (1983,1985).

Species	May		June		July		August		September	
	T	C	T	C	T	C	T	C	T	C
Common Loon <u>Gavia immer</u>	2	0	0	2			0	3		
American Bittern <u>Botaurus lentiginosus</u>	0	1			1	0				
Great Blue Heron <u>Ardea herodias</u>	0	1	1	2	1	0	0	1		
Wood Duck <u>Aix sponsa</u>	1	8	0	7					0	3
Green-winged Teal <u>Anas crecca</u>	0	2								
Mallard <u>Anas platyrhynchos</u>	0	1								
Blue-winged Teal <u>Anas discors</u>	1	0								
Red-breasted Merganser <u>Mergus serrator</u>			0	1						
Northern Harrier <u>Circus cyaneus</u>					1	0				
Sharp-shinned Hawk <u>Accipiter striatus</u>	0	1			1	1	1	0	0	2
Broad-winged Hawk <u>Buteo platypterus</u>	0	1	0	1	0	2	1	0	0	1
Red-tailed Hawk <u>Buteo jamaicensis</u>			3	0	1	2	2	2	1	0
Ruffed Grouse <u>Bonasa umbellus</u>	16	27	6	17	8	17	11	14	10	25
Sandhill Crane <u>Grus canadensis</u>	1	0								

## Appendix 5b (continued)

Species	May		June		July		August		September	
	T	C	T	C	T	C	T	C	T	C
Solitary Sandpiper <u>Tringa solitaria</u>							0	2		
Common Snipe <u>Gallinago gallinago</u>	1	0								
American Woodcock <u>Scolopax minor</u>			1	0	0	3	3	1	1	1
Yellow-billed Cuckoo <u>Coccyzus americanus</u>			0	1						
Great Horned Owl <u>Bubo virginianus</u>									0	1
Barred Owl <u>Strix varia</u>	2	0							2	0
Chimney Swift <u>Chaetura pelagica</u>	0	2			0	3				
Ruby-throated Hummingbird <u>Archilochus colubris</u>					1	0	1	1		
Belted Kingfisher <u>Ceryle alcyon</u>	1	0			0	1	0	1	0	2
Yellow-bellied Sapsucker <u>Sphyrapicus varius</u>	15	14	8	9	4	6	3	4	0	8
Downy Woodpecker <u>Picoides pubescens</u>	2	0	2	1	0	1	3	2	2	2
Hairy Woodpecker <u>Picoides villosus</u>	3	4	3	0	2	2	6	7	8	3
Black-backed Woodpecker <u>Picoides arcticus</u>	0	2	0	3			2	2		
Northern Flicker <u>Colaptes auratus</u>	9	4	3	3	6	1	5	3	4	3
Pileated Woodpecker <u>Dryocopus pileatus</u>			1	0			0	2	0	1

## Appendix 5b (continued)

Species	May		June		July		August		September	
	T	C	T	C	T	C	T	C	T	C
Olive-sided Flycatcher <u>Contopus borealis</u>	2	2	3	2	1	3				
Eastern Wood-Pewee <u>Contopus virens</u>	0	4	1	14	3	12	7	11		
Yellow-bellied Flycatcher <u>Empidonax flaviventris</u>	7	10	29	27	12	16	1	1		
Acadian Flycatcher <u>Empidonax virescens</u>					0	1				
Alder Flycatcher <u>Empidonax alnorum</u>			5	4			1	0		
Least Flycatcher <u>Empidonax minimus</u>	19	41	10	22	14	8	1	0		
Great Crested Flycatcher <u>Myiarchus crinitus</u>	7	7	4	6	0	3	0	3		
Eastern Kingbird <u>Tyrannus tyrannus</u>	0	1	0	1	1	3	5	2		
Tree Swallow <u>Tachycineta bicolor</u>	8	1	0	6						
Gray Jay <u>Perisoreus canadensis</u>	1	0	4	0	6	1	1	0	4	3
Blue Jay <u>Cyanocitta cristata</u>	44	38	26	17	11	26	22	22	27	56
American Crow <u>Corvus brachyrhynchos</u>	4	4	2	1	0	1	1	0	0	1
Common Raven <u>Corvus corax Linnaeus</u>	0	3			1	1	0	0	1	0
Black-capped Chickadee <u>Parus atricapillus</u>	44	39	17	22	40	69	76	92	85	92
Boreal Chickadee <u>Parus hudsonicus</u>	1	2	2	0			0	1	1	3

## Appendix 5b (continued)

Species	May		June		July		August		September	
	T	C	T	C	T	C	T	C	T	C
Red-breasted Nuthatch <u>Sitta canadensis</u>	2	3	20	8	21	33	25	22		
White-breasted Nuthatch <u>Sitta carolinensis</u>	4	7	1	1	0	5	2	3	3	3
Brown Creeper <u>Certhia americana</u>	8	4	6	15	7	10	9	31	10	15
Winter Wren <u>Troglodytes troglodytes</u>	14	16	18	13	15	18	2	3	4	8
Sedge Wren <u>Cistothorus platensis</u>	2	0	2	0	1	0	5	0		
Marsh Wren <u>Cistothorus palustris</u>	1	2								
Golden-crowned Kinglet <u>Regulus satrapa</u>	25	20	6	11	16	13	27	12	30	16
Ruby-crowned Kinglet <u>Regulus calendula</u>	6	2	2	0					10	1
Veery <u>Catharus fuscescens</u>	4	2	11	10	10	5	2	2	0	0
Swainson's Thrush <u>Catharus ustulatus</u>	33	41	0	7	0	1	0	0	6	10
Hermit thrush <u>Catharus guttatus</u>	34	28	22	37	64	54	10	6	2	5
Wood Thrush <u>Hylocichla mustelina</u>	1	2	0	2						
American Robin <u>Turdus migratorius</u>	20	20	8	7	8	13	5	4	7	7
Gray Catbird <u>Dumetella carolinensis</u>			2	1	0	1	1	2	0	1
Brown Thrasher <u>Toxostoma rufum</u>	1	1								

## Appendix 5b (continued)

Species	May		June		July		August		September	
	T	C	T	C	T	C	T	C	T	C
Cedar Waxwing <u>Bombycilla cedrorum</u>			0	2	3	1	5	30	0	
Solitary Vireo <u>Vireo solitarius</u>	10	14	6	3	4	3			2	1
Yellow-throated Vireo <u>Vireo flavifrons</u>			1	0						
Warbling Vireo <u>Vireo gilvus</u>									0	1
Philadelphia Vireo <u>Vireo philadelphicus</u>			1	0						
Red-eyed Vireo <u>Vireo olivaceus</u>	39	45	55	59	59	81	8	13	2	2
Golden-winged Warbler <u>Vermivora chrysoptera</u>	9	7	4	3	0	1				
Tennessee Warbler <u>Vermivora peregrina</u>	6	4								
Orange-crowned Warbler <u>Vermivora celata</u>			0	1					1	0
Nashville Warbler <u>Vermivora ruficapilla</u>	78	94	37	56	8	17	2	1	2	2
Northern Parula <u>Parula americana</u>	16	22	16	15	5	3				
Yellow Warbler <u>Dendroica petechia</u>	5	0	2	0			1	0		
Chestnut-sided Warbler <u>Dendroica pensylvanica</u>	82	43	73	50	29	4	0	2		
Magnolia Warbler <u>Dendroica magnolia</u>	2	1	3	0	0	2			0	1
Cape May Warbler <u>Dendroica tigrina</u>			1	1						

## Appendix 5b (continued)

Species	May		June		July		August		September	
	T	C	T	C	T	C	T	C	T	C
Yellow-rumped Warbler <u>Dendroica coronata</u>	33	39	15	7	8	5	12	3	54	28
Black-throated Green Warbler <u>Dendroica virens</u>	71	68	42	53	47	42	3	6	7	1
Blackburnian Warbler <u>Dendroica fusca</u>	17	12	2	12	2	5			1	0
Pine Warbler <u>Dendroica pinus</u>	2	0	1	0						
Palm Warbler <u>Dendroica palmarum</u>	5	1	3	0	1	0	3	0	3	2
Black-and-white Warbler <u>Mniotilta varia</u>	38	45	28	21	8	0	3	2		
American Redstart <u>Setophaga ruticilla</u>			3	0					2	0
Ovenbird <u>Seiurus aurocapillus</u>	132	166	79	121	25	36	20	26	1	7
Northern Waterthrush <u>Seiurus noveboracensis</u>	0	2	1	2						
Connecticut Warbler <u>Oporornis agilis</u>	2	3	3	0			1	0		
Mourning Warbler <u>Oporornis philadelphia</u>	3	7	19	16	6	1	3	2		
Common Yellowthroat <u>Geothlypis trichas</u>	25	22	23	22	35	22	1	1	0	1
Canada Warbler <u>Wilsonia canadensis</u>	3	5	8	7	1	1	0	2	1	0
Scarlet Tanager <u>Piranga olivacea</u>	3	7	5	1					0	1
Rose-breasted Grosbeak <u>Pheucticus ludovicianus</u>	9	15	14	12	3	6	6	0	0	1



## Appendix 5b (continued)

Species	May		June		July		August		September	
	T	C	T	C	T	C	T	C	T	C
Indigo Bunting <u>Passerina cyanea</u>			6	0	8	0				
Chipping Sparrow <u>Spizella passerina</u>	17	4	15	2	6	0	0	1		
Lark Sparrow <u>Chondestes grammacus</u>	3	0								
Song Sparrow <u>Melospiza melodia</u>	23	12	21	8	8	13	4	0	2	2
Lincoln's Sparrow <u>Melospiza lincolnii</u>			1	0	3	0				
Swamp Sparrow <u>Melospiza georgiana</u>	8	1	8	0	7	0	2	0	1	1
White-throated Sparrow <u>Zonotrichia albicollis</u>	65	70	56	48	58	57	6	13	30	37
Dark-eyed Junco <u>Junco hyemalis</u>			2	1	4	0			3	2
Red-winged blackbird <u>Agelaius phoeniceus</u>	5	4	3	2	1	1				
Brewer's Blackbird <u>Euphagus cyanocephalus</u>			0	3						
Common Grackle <u>Quiscalus quiscula</u>	2	9	10	0	0	1				
Brown-headed Cowbird <u>Molothrus ater</u>	1	0	1	1						
Northern Oriole <u>Icterus galbula</u>	0	2								
Purple Finch <u>Carpodacus purpureus</u>	5	3	0	5						
Pine Siskin <u>Carduelis pinus</u>	0	2								

## Appendix 5b (continued)

Species	May		June		July		August		September	
	T	C	T	C	T	C	T	C	T	C
American Goldfinch <u>Carduelis tristis</u>	7	6	1	5	4	5	2	4	2	3
Evening Grosbeak <u>Coccothraustes vespertinus</u>					1	6				
Unidentified passerine	17	26	10	12	41	33	69	86	64	51
Unidentified woodpecker	10	13	10	6	2	11	7	5	7	9
Unidentified non-passerine	1	0	0	1			1	2		
Total individuals	1105	1142	818	839	644	693	400	461	403	426
Total species <sup>a</sup>	68	69	68	62	53	55	47	44	36	43

<sup>a</sup>Does not include unidentified birds.

I. COVER PAGE

A. SUBCONTRACTOR: MICHIGAN STATE UNIVERSITY  
EAST LANSING, MICHIGAN 48824

B. SUBCONTRACT NUMBER: E06595-88-C-007

C. TITLE OF REPORT: ELF COMMUNICATIONS SYSTEM ECOLOGICAL  
MONITORING PROGRAM ANNUAL REPORT FOR  
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5.10

D. REPORTING YEAR: 11/1/87 - 10/31/88

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## II. FRONTISPAGE

- A. Subcontractor: Michigan State University  
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- B. Subcontract Number: E06595-88-C-007
- C. Title of Report: ELF Communications System Ecological  
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- D. Reporting Year: 11/1/87 - 10/31/88
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#### IV. GLOSSARY AND ACRONYMS

AFDW-biomass - ash-free dry weight of organic matter that accumulates on rock or other substrate surfaces on the stream bottom. This organic matter is produced by algae, bacteria, and fungi and/or by the flocculation and settling of suspended organic matter from the water column.

Alkalinity - a chemical measure of the amount of anions in the water determined by titration with dilute acid; a rough measure of the acid neutralizing capacity of the water derived primarily from the carbonate and bicarbonate ions in it.

ANOVA - analysis of variance; a statistical procedure for comparing whether treatment means are essentially the same or not; it is essentially an arithmetic process for partitioning a total sum of squares into components associated with recognized sources of variation.

BACI - Before and After, Control and Impact analysis - statistical analysis which compares differences between control and impact sites, both before and after antenna operation by comparing differences in the variance for each site before and after the operation of the antenna (see Stewart-Oaten et al 1986 for details - reference section of element 2).

Backcalculated length - a method for calculating the length of fish at previous age from scales or otholiths. Length is estimated from a body-scale relationship between distance between annuli on scales or otoliths and fish length at capture.

Benthos (Benthic) - organisms that live on or in the river bottom in or on substrates such as sand, gravel, and organic detritus.

Biomass - the weight of a population of organisms, or of some defined portion of it such as an individual or a size class.

Body-scale relationship - an empirically determined relationship between length of fish and the distance between annuli on scales or otoliths; used in backcalculation of length.

Biovolume - a crude estimate of biomass of algal cells where volume is calculated from the shape and size of individual cells using geometric formulae. Individual cell volumes are then multiplied by algal species counts and summed to get total biovolume.

Catch rates - the catch of fish, in numbers or in weight per defined unit of fishing effort.

C.C. - correlation coefficient ( $r$ ); a measure of the degree to which variables vary together or a measure of the intensity of association.

C-F - collector-filter-feeding aquatic invertebrates; invertebrates that feed by collecting particles of detritus or algae from the water by use of nets or other collecting devices.

C-G - collector-gatherer aquatic invertebrates; invertebrates that feed by collecting detrital particles from substrates in the river.

Chi-square test - statistical test for goodness of fit for observed and expected frequencies.

Chlorophyll  $a$  - the primary photosynthetic pigment of most plants; in this study, it is extracted using acetone and used as a crude measure of plant productivity or standing crop.

Conductivity - a measure of the ionic strength of the water.

CPUE - the catch of fish, in numbers or in weight per defined unit of fishing effort.

C.V. - coefficient of variation; a quantity of use to the experimenter in evaluating results from different experiments involving the same character but possibly conducted by different persons.

Degree days - daily accumulation of degrees ( $^{\circ}$  C) above a pre-set threshold value (in our study the threshold was  $(2^{\circ}$  C).

DeLury method - removal method of population estimation. Population is estimated from the relation of fishing success to cumulative fishing effort. Assumes fish catchability does not change throughout all sampling passes, and the population is significantly reduced with each pass. Three removals were used in this study.

Diatoms - a group of algae that often dominate unpolluted rivers (very few other kinds of algae are present in the Ford River most of the time); they are characterized by having the cells encased in two silaceous covers known as valves.

Discharge (Q) - the amount of water passing a particular point on a river over a given time period, usually expressed in cubic meters per second; it is calculated from measurements of width, depth, and velocity by taking at least 20 verticals of depth, mean velocity, and the width between the verticals across a stream or from depth measurements based on depth(stage)-discharge relationships determined empirically for the river segment being studied.

DO - Dissolved Oxygen; the amount of oxygen dissolved in water.

Electrofishing - method used in fisheries to collect/capture fish. Electric current is applied to the water which temporarily incapacitates the fish so that they can be collected.

Electrofishing efficiency - percent of the total population of fish taken by electrofishing crew.

ELF - Extremely Low Frequency electromagnetic radiation; it is derived primarily from local electric power lines or from the ELF antenna that will be used by the Navy to communicate with submarines at sea.

EPROM - Erasable Programmable Read Only Memory chip; the type of chip used to temporarily store data in the Omnidata data pods used in our ambient monitoring program; these data are transferred by use of an EPROM reader into an Apple computer and summarized.

FCD - Ford Control Downstream - site on Ford River presently used as the control site (see Fig. VII.1).

FCU - Ford Control Upstream - site on Ford River originally considered as a control site. Presently in use as a site for monitoring movement of fish into one of the two primary tributaries of the Ford River above our test and control sites (see Fig. VII.1).

FEX - Ford Experimental - site on Ford River presently used as the primary experimental or test site; it is located where the N-S leg of the ELF antenna crosses the Ford River (see Fig. VIII.1).



FFG - Functional Feeding Groups - aquatic insects species are categorized into feeding groups according to their predominant feeding mode (See Merritt and Cummins, 1984 - reference after element 4).

FS1 - Ford Site 1 - site on Ford River presently used occasionally for fish movement studies and for monitoring changes in fish populations in cooperation with the Michigan DNR (see Figure VII.1).

Freidman's test - non-parametric test comparing distributions; the null hypothesis being that the populations within a block are identical against the alternative that at least one treatment comes from populations which have a different location in one direction.

Fyke net - passive trap nets at FCD and FEX. Set in tandem, one capturing upstream migrants the other capturing downstream migrants. Nets block entire width of stream and are very portable and used in areas with unstable substrate.

Grazer - as used in this study; an invertebrate herbivore that feeds on algae on rocks and other substrates on the stream bottom.

Gross Primary Production (GPP) - the total amount of energy fixed by green plants in the process of photosynthesis in a given time period; it is equal to plant respiration plus net primary production.

Growth - incremental increase in mean length and weight. Backcalculation of lengths and body-scale relationship were used to monitor growth in this study.

H' - taxon diversity (after Shannon-Weiner). An information theory index which weights the number of taxa and the apportionment of numbers of individuals among the taxa.

Handling (tagging) mortality - mortality caused by weighing, measuring, tagging, etc. Calculated from recaptured fish found dead in the gear in this study. Probably underestimated.

Hardness - a rough chemical measure of the amount of cations in the water determined by titration.

Holobiotic - an organism that spends its entire life in one environmental medium; e.g., an aquatic beetle, Optioservus sp., whose larval and adult stages are aquatic.

J' - taxon evenness (after Shannon-Weiner). An index which evaluates the apportionment of numbers of individuals within each taxon.

-k/day - processing coefficient. An exponential decay model describing the rate biological material (in our case, leaves) decays per day,  $\log_e$  (% remaining/100/)days.

Kruskal-Wallis test - non-parametric statistical test comparing distributions; the null hypothesis being that the populations sampled are continuous and identical, except possibly for location.

Lee's Phenomenon - commonly seen in backcalculated length estimates. In the larger fish, backcalculated lengths at early ages are less than the true average size at that age. Usually due to differential growth or mortality. Reverse Lee's Phenomenon can occur also, especially in non-exploited populations or where predator-prey relationships do not exist or are poorly defined.

Lincoln index - an estimate of population size based on the proportion of marked organisms that are captured in a later sampling effort (see Southwood, 1978 - see references after element 2).

Mann-Whitney U test - non-parametric statistical test of two samples which gives rise to a t-test or ANOVA. Null hypothesis is that two samples come from populations having the same distribution.

Mark-recapture studies - a method for determining population size or movement of organisms based on recapture of marked individuals.

MDW/IND - mean dry weight (mg.) per individual.

N - Nitrogen when used as follows (otherwise refers to the number of samples taken):

- ammonium-N: ammonium-Nitrogen
- nitrate-N: nitrate-Nitrogen
- nitrite-N: nitrite-Nitrogen
- inorganic-N: inorganic-Nitrogen; the sum of the three N species above.
- organic-N: organic-Nitrogen; total Kjeldahl nitrogen minus ammonium nitrogen.

Naiads - the immature (nymph) stages of insects that undergo

incomplete metamorphosis; e.g. dragonfly naiads.

Net Primary Production (NPP) - the amount of energy or carbon that is fixed by the process of photosynthesis that is not used in self maintenance (respiration) by the plant; it supports herbivore or detritivore food chains.

Numerical dominance - the ratio between numbers of individuals from one taxon and the total numbers of individuals found in a sample. The percentage gives the numerical dominance of that taxon.

P - predators; animals that ingest other animals.

PAR - Photosynthetically Active solar Radiation = solar radiation that most plants are able to use in photosynthesis; similar to visual range for humans.

PCA - Principal Components Analysis; a statistical procedure used to ordinate data in relation to environmental variables.

Percent recapture - the ratio between numbers of marked animals recaptured and the total number of animals marked.

Periphyton - algae, bacteria and fungi attached to the substrate, rocks, twigs or any other debris in the stream. Our studies emphasize periphytic algae attached to bottom substrates.

Phaeophytin a - the breakdown product of chlorophyll a; the ratio of chlorophyll a to phaeophytin a is sometimes used as a very crude estimate of the health of algal populations.

Predators - animals that ingest other animals.

Relative weight (Wr) - weight at length values calculated from fish being studied. Used in comparative analysis of condition against weight at length values calculated from populations in the literature.

S - shredder invertebrates; those that feed on large leaf fragments by shredding holes in this leaf material.

S - taxon richness. The number of taxa in a sample.

Shannon-Wiener diversity - diversity index which uses number of species and abundance within species to compute a values which is comparable between sites and years (see H' above).

Shredder - see S (first definition) above.

Standard weight (Ws) - mean weight at length values calculated from a number of populations from the literature. Wr values are measured against these values to comparatively determine the condition of fish being studied.

TB - total biomass; total weight of all organisms in the taxa being discussed.

TM - Two Mile Creek - one of the two principal tributaries of the Ford River above our two primary study sites; presently used for fish movement studies (see Fig. VII.1).

T-test - statistical test of the difference between two means to analyze variance.

Turbidity - a measure of the light blocking particles suspended in the water.

Univoltine - one emergence per year.

Weir - semi-permanent traps used to capture fish. Made of hardware cloth held in place with metal rods. Installed at beginning of study season and removed at the end of the season; installation is similar to that described for fyke nets above. Weirs intercept fish moving up or downstream. Fish are captured in removeable weir boxes when these boxes are in place. When boxes are removed, weir is negotiable by all fish.

Wr - relative weight condition factors used in fish studies.

Yearling fish - fish that are one + years old but are not yet sexually mature.

YOY - young of year; fish hatched out earlier in the year.

## V. ABSTRACT

The goal of the aquatic ecosystems project is to determine the effects of low-level, long-term, electromagnetic radiation on the biota of streams. This electromagnetic radiation will be derived from the U.S. Navy's extremely low frequency submarine communication system (ELF) located in the upper peninsula of Michigan. The specific ecosystem being studied is the Ford River, a fourth order stream that arises in northern Dickinson and southern Marquette Counties and enters the Michigan portion of Green Bay south of Escanaba, Michigan. Detailed ecological sampling and analyses are being conducted simultaneously at two sites. The control site (FCD) is located on a fourth order section of the Ford River in northern Dickinson County just west of the community of Ralph, Michigan. It is approximately five miles downriver from the test site (FEX) where the N-S leg of the antenna system crosses the river. Engineering projections indicate that the control site will receive 8-10 fold less electromagnetic radiation from the antenna than will the test site after the system is fully operational. These two sites were closely matched in terms of electromagnetic exposure from local electric power distribution lines prior to construction and operation of the antenna. Data collected to date are either preoperational data (June, 1983 to June, 1986) or transitional data (July, 1986 through 1988) with exposure to ELF radiation restricted to daylight hours at 4-6 amps for several days from July to October, 1986, or at 15 amps for several days from April 28 to November 15, 1987, or at 75 amps for most working days during 1988. The system will eventually be operated at 150 amps for 24 hours per day.

The ecological monitoring program consists of four primary components. These include: (1) an extensive program of monitoring chemical and physical environmental data for the two sites; (2) a program to determine ELF effects on the algal communities attached to the rocks on the river bottom; (3) a program to determine ELF effects on the aquatic insects; and (4) a program to determine ELF effects on the fish community with emphasis on fish movements between sites. The two primary sites (test and control, FEX and FCD) are very closely matched both physically and chemically. Data routinely monitored at each site include discharge of water, temperature of the water and air, photosynthetically active solar radiation (PAR) received above and below the water surface, pH, dissolved oxygen, alkalinity, hardness, turbidity, and nutrients used by the plants such as nitrogen, phosphorus, and silica. Paired t tests indicate either that there are no differences between sites for most parameters or that slight differences exist that probably have no effect on the biota (for example, discharge increases slightly, but significantly ( $p < 0.05$ ) from the upstream test site to the downstream control site).

Data collected on the algal community includes chlorophyll a standing crop and accrual rates, organic matter standing crop and accrual rate measured as ash free dry weight accumulation on microscope slides, diatom density, diatom individual cell volumes, diatom total biovolume, diatom community diversity and evenness, and data on percent dominance by the major diatom species. No differences in any of these parameters have been detected between the data collected before operation of the antenna and the transitional data that can be attributed to ELF effects using paired t tests. A before and after control and impact statistical procedure (BACI) demonstrated that differences do exist between the before and after (transitional) data for some of these parameters. These differences appear to be more related to differential site responses to weather related variables such as temperature and discharge than to ELF effects. Studies on the effects of grazing invertebrates on the algal communities have yielded comparable results for the two sites with grazers causing shifts in community composition in some years but not in others.

Data collected on the aquatic insect communities include: (1) data on species richness and biomass of stream insects associated with bottom materials (sand, gravel, pebble, cobble); (2) data on leaf processing rates derived from studies of leaf packs placed on the leading edge of bricks in the streams, and (3) studies of movement by the immatures of a species of dragonfly (Ophiogomphus colubrinus). The insect communities associated with bottom materials show distinct seasonal patterns, but no difference in taxon diversity, evenness, or species richness can be related to ELF effects either for the entire community or for individual functional feeding groups. The leaf pack studies include separate studies of freshly picked green leaves and leaves collected after leaf fall in the autumn from speckled (tag) alder (Alnus rugosa) leaves. These studies also include studies of the insect communities associated with these leaf packs with special emphasis on three species of mayflies (Ephemeroptera) and a species of stonefly (Plecoptera). None of the parameters monitored as part of the leaf pack studies show any differences that can be related to ELF effects. The studies of movement of the dragonfly did yield some puzzling results in 1988 (increased movements at the test site on a couple of days) that might be related to ELF effects. However, these preliminary results must be repeated and corroborated before we can be certain that this is the case. It seems more likely that the low discharge and high temperatures characteristic of 1988 may have had differential effects at the two sites causing differences unrelated to ELF effects.

Studies of fish emphasize movement of brook trout

(Salvelinus fontinalis) with much of the data collected with 1/2 inch mesh, directional fyke (trap) nets or weirs constructed of 1/2 inch hardware cloth. Catch statistics for all species caught by this gear are kept and used to generate data on community composition and abundance as well as data on age, length, growth, and relative condition of individual species. Eighteen species were collected at the test site (FEX) in 1988, while 21 species were collected at the control site (FCD). Overall, the species composition and diversity were similar at the two sites with only changes seen in the rare species. There was no significant difference in either numbers of fish caught or biomass caught between the two sites. Growth and condition factors were calculated for several of the more common species and compared to literature values. Most species in the Ford River grow slower than the average for the species reported in the literature. Brook trout movement has varied widely from year to year as a function of stream temperature. The fish move upstream when water temperatures exceed 16 ° C for any extended period of time. Gear calibration and population estimates have been conducted at areas at least a mile upstream of the test and control sites using electrofishing equipment. The population estimates vary widely during the year and from year to year with low numbers occurring during times when the trout and several other species move upstream of the river sections being studied because of high water temperature. No effect of transitional operation of the ELF antenna has been detected on the fish community or on fish movement.

Overall, we have detected no changes in the aquatic community that we can relate statistically with confidence to transitional operation of the ELF antenna. We monitor a wide variety of population and community level parameters for the algal, insect and fish communities. Many of these have low enough coefficients of variation between the control and test sites to allow us to detect relatively subtle (20 to 30 %) differences should such differences occur once the ELF antenna is fully operational.

## VI. SUMMARY

This research project is directed at determining the effects of low-level, long-term, electromagnetic fields (ELF) on natural stream ecosystems and their associated plant and animal life. Detailed ecological sampling and analyses are being conducted simultaneously at two sites: (1) a control site, FCD, and (2) an experimental site, FEX, at the corridor of the ELF antenna. These sites have been studied since 1983 with additional sites monitored for studies of fish movements. The N-S leg of the ELF antenna crosses the FEX site and was tested at 4-6 amps for several hours on several days from July to October, 1986; at 15 amps during part of several days between April 28 and November 15, 1987; and at 75 amps for most working days during 1988. Thus, data collected to date represent data collected prior to any exposure from the operation of the antenna (June 1983 through June 1986) or represent transitional data with variable operations and exposures to electromagnetic radiation (July 1986 to present). These transitional period data have only included exposure during daytime for short time periods with exposure at half the final proposed operating amps (150) or less. Even so, some initial analyses on the effects of these exposures to the biota have been included in this report.

### Element 1- Conduct Ambient Monitoring Program

Data for all chemical and physical parameters demonstrated that the experimental and control sites were very well matched. For the majority of the parameters, there were no significant differences between sites. When significant differences did occur between the chemical constituents, they usually involved a slight increase in a downstream direction. This trend had been true for hardness, nitrate, and organic nitrogen prior to this year. This year the differences for nitrate and organic nitrogen disappeared. The differences observed for hardness, nitrate, and organic nitrogen in prior years could be related to an expected accumulation of dissolved load in a downstream direction or to local land use differences between sites. Whatever the cause, the differences were small and probably would not lead to significant intersite differences in productivity. We initiated experiments in 1987 to determine the impact of N and P inputs on the algal community. Both had to increase before significant changes in the algal community occurred. Clearly, no such shift in N and P has occurred.



Dissolved oxygen was only slightly below saturation at both sites and was slightly but significantly higher at FEX than it was at FCD for data reported prior to 1988. We postulated that this difference was probably related to differences in sample times between the two sites. In 1988, we alternated sampling times for the two sites and differences between sites disappeared.

Chloride also was slightly but significantly higher at FEX than it was at FCD prior to 1988. This difference might reflect a slight amount of road salt influence from Highway M-95 at Channing, MI that is diluted in a downstream direction. This previously observed difference between the two sites did not occur in 1988. Even at FEX, chloride levels were only slightly higher than typical rainfall values. Thus, chloride should have little effect on the biota at either site.

Chemical and physical parameters for FEX and FCD demonstrated that these two sites were very similar with significant differences between sites showing up for less than one-third of the parameters monitored prior to 1988. The differences that did occur were slight and should have little impact on site productivity. Most of these differences disappeared in 1988 with the exception of water temperature and hardness.

Element 2- Monitoring of Species Composition, Numbers, Diversity, Biomass Production, Cell Volume, and Chlorophyll a/Phaeophytin a Production for Periphyton.

1. Chlorophyll a

Annual patterns for chlorophyll a standing crop and accrual were characterized by large year to year variability. The only consistent trend was for July-August peaks in most years and winter lows. The magnitudes of peaks also varied between years. Paired t-tests for 1987-88 data showed no differences between our control (FCD) and experimental sites (FEX) nor were there any differences for all data collected since 1983. "Before" (6/83-4/86) and "after" (5/86-9/88), control (FCD) and impact (FEX) (BACI) analyses showed that there has been an increase in chlorophyll a since the testing of the antenna began. However, lack of differences between sites for the after years coupled with significant positive correlations between water temperature and chlorophyll a and increasing water temperatures during the drought periods in the spring and summer in 1986, 87, and 88 lead us to believe that these differences are related to weather variables and

not to ELF exposure.

## 2. Organic Matter

Organic matter (AFDW-biomass) standing crop and accrual rates showed considerable year to year variability similar to chlorophyll *a*. These parameters have been consistently characterized by showing no significant differences between sites since 1983. BACI analyses also showed that no difference has occurred in AFDW-organic matter accumulation since the testing of the antenna began in 1986. The only overall trend has been for a July-August peak in standing crop and accrual rates and winter time lows for both standing crop and accrual. Organic matter standing crop was significantly ( $p < 0.05$ ) positively correlated with water temperature and chlorophyll *a*, and negatively correlated with discharge and dissolved oxygen. It was also significantly, positively correlated with chlorophyll *a*.

## 3. Chlorophyll a to Phaeophytin a Ratios

This ratio continued to vary widely throughout the year in 1986-87. It proved to be more predictable in 1987-88. Even so, the random nature of the fluctuations appear to indicate that this parameter will not be useful for detection of ELF effects.

## 4. Diatom Cell Density

Diatom cell density continued to be characterized by no statistical difference between sites, regardless of length of data set compared according to paired t tests. However, BACI analyses indicated that data collected before 4/86 were significantly different from data collected after 4/86. The increased density after 4/86 may be due to higher temperature and lower discharge associated with extremely dry conditions during May and early summer in each of these years. Density was highest in May in all three years and was higher in 1988 than in any year prior. The effect of weather was suggested by the significant positive correlation with water temperature. Density was also positively correlated with chlorophyll *a* and negatively correlated with evenness and diversity.

## 5. Species Diversity and Evenness

Diatom species diversity and evenness were not significantly different in 1988 or for all data collected to date according to paired t tests. Annual trends show a high

diversity and evenness during winter (except winter of 1986-7) and lower values during the summer periods. In 1988, we calculated percent abundance for all species of diatoms and presented data for all species that achieved dominance greater than 10 % for any season. Only two species, Achnanthes minutissima and Cocconeis placentula, achieve such dominance in the summer, and the same two species have been dominant each summer since the start of the study. From three to five species achieve such dominance in the winter, and these three change from winter to winter. BACI analyses were presented for five species of diatoms and showed that few differences have occurred before and after antenna testing began. Even so, overall diversity and evenness have changed significantly over that time period according to the BACI analyses. Because of the pattern of year to year differences, we suggest that these changes may be related to weather rather than ELF effects.

#### 6. Total Biovolume and Individual Cell Volume

Individual cell volume comparisons of diatoms between sites showed no significant differences according to paired t tests. There were also no differences in before and after data according to BACI analyses. Total biovolume was also not significantly different between sites for 1988 or between before and after data sets. In general, average cell volume was high in winter and low in summer, whereas total biovolume tended to be highest in summer since it is the product of average volume times density. Average cell volume was negatively correlated ( $p < 0.05$ ) with water temperature and positively correlated with total biovolume. Total biovolume was positively correlated with chlorophyll a and negatively correlated with diversity and evenness.

#### 7. Correlation with Environmental Variables

A correlation matrix was generated using all the available data collected from each individual site over the past five year period. Although some water chemistry parameters appeared to influence the biological parameters at one site more than another, there was generally amazing agreement between sites regarding the influences of either environmental factors, or water chemistry constituents. The results of the correlations also agreed with our previously reported analyses using multiple regression analyses. Some of these correlations have been presented in the summary above and were included this year in the discussion of each biological parameter.

## 8. Photosynthesis-Respiration Studies

Net production, respiration, and gross production of the community on rock surfaces did not differ greatly between sites. The lack of significance reported in last year's report between sites for 1984, 1985, and 1986, plus the data from 1987 and 1988, indicate that this parameter may offer a precise means of detecting ELF effects on community metabolism.

### Element 3- Effects of Insect Grazer Populations on Periphyton Communities.

Grazing macroinvertebrates can change the composition of the diatom community at densities equal to or greater than densities found in the Ford River. Specifically, Glossoma nigrum, a grazing caddisfly, caused a shift in dominance within the diatom community in 1985 and 1986 with Cocconeis decreasing in abundance and Achnanthes increasing in abundance as grazing pressure increased. Such shifts in community structure occurred at both FEX and FCD despite no significant changes in community based parameters such as chlorophyll *a* or AFDW-organic matter biomass accumulation. Results from 1985 were somewhat different from results from 1986. In 1986, the trend towards decreased abundance of Cocconeis and increased abundance of Achnanthes occurred at both sites but was not as significant as in 1985. In 1987, there was no measurable impact of grazers on any aspect of the periphyton community with the possible exception of shifts in dominance of a couple of minor taxa at FEX. Between year differences in the impact of grazers on the periphyton communities in our streamside channels may be due to variation in the silt load encountered during the course of the studies. We plan some minor modifications in procedures to avoid such potential confounding problems in the future.

### Element 4 - Species Richness and Biomass of Stream Insects from Artificial Substrates in Riffles

Taxon diversity ( $H'$ ), evenness ( $J'$ ) and richness ( $S$ ) showed consistent depressions during winters and early springs and peaks during summers over the entire five year period. Both water temperatures and discharge were correlated with diversity and richness at FEX and FCD from the spring to late fall each year. From 1986 onward, summer peaks lasted longer than in previous summers. The enhanced duration appears more related to mild winters of 1986 and 1987 than to any other factor, including activation of ELF lines in the summer of 1986. Future data and analysis will

be used to test this assumption. Numbers of individuals also were higher in those latter years than in previous years. This was especially evident at the experimental site, FEX.

High chironomid abundances greatly affected  $H'$  and  $J'$  and are highly correlated with those two parameters. The effects of chironomids on  $H'$  and  $J'$  were most pronounced at FCD, owing to the higher ratios of chironomid abundances relative to other species abundances. When chironomids were excluded from benthic insect analysis, correlation coefficients for  $J'$  with respect to  $H'$  were lower -- especially at FCD, which is the site containing high numbers of chironomids relative to other species abundances. This indicates that high numbers in the Chironomidae biases  $H'$  and  $J'$ . If we had time to separate the family to species level, this bias would be erased.

Distinctive seasonal patterns were found for insect total biomass over a five year period. These patterns were highly correlated with diatom densities and water temperatures at FEX and FCD combined. From the summer of 1986 onward, the patterns showed less similarity. Underwater solar radiation and water discharge was more correlated with total insect biomass and diatom density from late spring through late fall each year than were water temperatures. However, when the entire years' data were analyzed, water temperatures alone had higher correlations with insect biomass and periphyton density than did the other two physical factors.

Functional feeding groups (F.F.G.) were separated from insect total biomass values for analysis. Collector-gatherers showed the highest correlation coefficient values at FEX versus FCD. This functional feeding group contains many species that are being analyzed for changes in mean dry weight per individual values (MDW/IND; changes in growth) and for changes in numbers of individuals. All of the seven functional feeding groups are being monitored over time at both sites. From the data available, there appears to be no effect of ELF on those functional feeding groups. More data after ELF activity are required before substantiation of that view is supported.

Changes in MDW/IND values were consistent for the seven taxa monitored. The variance for the values are low, and if ELF affects any of those taxa, effects should be detected.

#### Element 5 - Movement Patterns of Selected Aquatic Insects

Percent recapture success steadily increased over the years owing to improvements in sampling techniques: 1) always having two people with handscreens adjacent to one another when sampling (initiated in 1986), and 2) constructing a baffle directly upstream of release sites to facilitate quick

settling of marked animals (initiated in 1987). In 1986 half of the 48 hr recapture were confounded by sampling between 24 and 48 hrs. Reporting of animals not recaptured after 24 hrs but recaptured after 48 hrs is no longer done. Animals undetected in their recapture "day" are recorded but those numbers are not reported.

Median distances moved were generally shorter in 1987 and 1988. Addition of a baffle to reduce flow rates at the release quadrat for One-half hour during release of the animals may have helped animals to settle and adhere. Even though handscreens held below the release site caught floating marked animals for re-release, reduced disturbance at initial releases appeared to enhance settling.

Movement patterns of the animals varied within and between sites over the years. As variability was high prior to and after E.L.F. activity, an increase in numbers of marking series at both sites for future years will be necessary to determine if E.L.F. differentially affects movements of the dragonflies.

Naiads of *O. colubrinus* travelled in a downstream direction at both sites for all mark-recapture studies. Percent recapture success is high (usually from 40 to 50%) making us rather confident that the data reflect the actual movement patterns of this predator. Yearly and seasonal variation in distances travelled by the dragonflies at each of the sites has prompted us to initiate more series in future years in efforts to separate temporal variability from possible E.L.F. effects.

#### Element 6 - Leaf Litter Processing

Leaf processing rates (-k) for fresh or autumn leaves at each of the sites were similar for all the years. Fresh leaves were processed fast; whereas, autumn leaves were processed at intermediate to slow rates. Diversity and evenness values were similar in 1982, 1984 and 1987 with an increase for the first month and thereafter a decrease in the index. In 1985 and 1986 there was a steady decrease after the first 9 days. Numbers of species (S) peaked by the end of a months incubation of leaves and diminished for all years. Percent dominance of chironomids on leaves was similar for all the studies except for a slight depression after three weeks incubation of the leaves. Mean number of individuals increased through the first month and then decreased by the end of the second month for all the studies. Total biomass of insects, adjusted to leaf mass consistently increased over time on fresh and autumn leaves at both sites. Highest biomass values were generally found at FEX. When

there were treatment differences, the highest biomass values were found of fresh rather than autumn leaves. Although there are differences between FEX and FCD with respect to biomass of insects, the differences remained "stable" throughout the years. Any deviations from past patterns that occur at FEX after E.L.F. is fully operational will be suspect unless obvious non-anthropogenic environmental alterations have occurred. MDW/IND values for four species showed consistent increases over time. Because leaves were put in FEX and FCD earlier in 1987 than in previous years, the values were lower; however, the patterns of change across years remained the same for Ephemera invaria, E. subvaria, Paraleptophlebia mollis and Isoperla transmarina. If changes in growth patterns for these species occur at FEX only after E.L.F. becomes fully operational, effects of E.L.F. on growth rates of those species should be detected.

## Element 7 - Fish Community and Abundance

### 1 Species Composition

Eighteen species from six orders and eleven families were collected at FEX in 1988. This represents an increase of one order, one family and two species from previous years. Twenty one species from eleven families and six orders were collected at FCD in 1988 with an increase of three species from previous years. Overall, the species composition was similar at the two sites with the only changes seen in rare species.

### 2. Species Abundance

Numerically and by biomass, the fish community was dominated by five species. Numerically, common shiners and creek chubs made up over 55 % of the catch at both sites. Burbot catch was the least variable, and common shiner, creek chub and brook trout catches were the most variable. By biomass, white suckers and brook trout were the dominant species at FEX, making up 40.6 % of the catch. At FCD, creek chubs and white suckers comprised 68.5% of the catch. Brook trout and white sucker catch in biomass was the most variable. Catch in biomass was more variable from year to year than catch in number. Overall, the fish species composition was similar from site to site and from year to year. Species diversity decreased at both sites in 1988 from previous values. No significant differences were found between sites, and the diversity values ranged between 1.54 to 2.2.

### 3. Catch Statistics

Catch rates (catch per day) were variable for all species and were seasonally dependent. Catch rates for common shiners and creek chubs increased dramatically in 1987 then decreased to average rates in 1988. White suckers catch rates at FEX also increased in 1987 then decreased in 1988. Brook trout and burbot continued negative trends in catch rates at FCD. Brook trout, burbot and white suckers all demonstrated similar catch rates at both sites and the differences can be attributed to increased habitat heterogeneity at FCD. The mean length of most species showed no consistent year to year trends at either FCD or FEX, and brook trout, creek chubs and white suckers at FCD were significantly larger than their FEX counterparts.

### 4. Fish Community Mobility

Most non-salmonid fish species with adequate sample sizes demonstrated site to site movement with most species showing a non-marking site recapture rate of 11.4 %. Recapture percentages for 1988 were average when compared to previous years. Overall, site to site movements were lower in 1986, 1987 and 1988 than the previous years which may be attributed to significant discharge changes in these years.

### 5. Individual Species Analyses

Age, growth, and condition factor analyses using common shiners, creek chubs, northern pikes, and white suckers were initiated as section of this element in 1986 with the premise that these factors are good indicators of the fish stress. Growth analysis using scales indicated that common shiners and creek chubs show better than average growth when compared to literature values. White suckers and northern pike both displayed poor growth when compared to literature values. Fish condition was examined using relative condition factors. Standard weight formulae were derived for common shiners, creek chubs, and white suckers from literature data. Common shiner condition was above the species average in each year. Creek chubs and white suckers demonstrated below species average condition ( $Wr = 87 - 92$ ). Creek chub condition factors declined from 1983 - 1987 by 5 % and then increased slightly in 1988. Common shiner condition showed a cyclic trend from 1983 - 1986 with a modulation of 7% per year then maintained a lower condition above the species mean for 1986 - 1988. White sucker condition improved by 8% since 1986.



## 6. Fixed Gear Calibration

This new study is designed to determine a functional relationship between fixed gear catch and actual fish densities. Net and weir catches can then be used to more accurately determine fish densities in the Ford River. DeLury estimates showed that fish densities and biomass declines from upstream sites to downstream sites. Also pre-movement (spring) populations and biomass are higher than post-movement estimates at all sites. Regression analysis of the relationships in this section will be reported after the 1989 season.

### Element 8 - Brook Trout Movement

#### 1. Movement Patterns and Rates

Brook trout catches peaked in spring-early summer at all sites except FCU. The peak occurred in June in 1984, 1987 and 1988 and in July in 1985 with the movement in an upstream direction. Peak catches of 1984, 1985, 1987 and 1988 were not seen in 1986. Brook trout movement appeared to be caused by mean water temperature exceeding the optimal growth temperature ( $16^{\circ}\text{C}$ ) and the rate of this increase which is related to acclimation time. Low groundwater discharge and river flow volumes also may create thermal barriers to movement. Groundwater recharge and spring precipitation are also important variables. Brook trout ( $>190\text{ mm}$ ) move from FCD and FEX upstream to the TM site based on a total of 520 tagged and branded fish. In 1984 and 1985, TM was chosen over FCU on the basis of the mean temperature being closer to optimal growth temperature. Recapture rates were consistent from 1984 to 1985 with no movement found in 1986 and little in 1987 and 1988. Movement rates were found to range between 1.1 to 5.0 km/day. Ranges from FEX to TM were similar between 1984, 1985, and 1987 with no catches between these sites in 1986 and 1988. Brook trout movement rates were greater in 1985 than in 1984 from FCD to TM with no movement detected in 1986 and 1988 and little in 1987. Angler tag return data verified the above movement rates indicating the fish move at a constant measureable rate upstream.

#### 2. Population Analysis

Michigan Department of Natural Resources conducted four electrofishing surveys at two sites on the Ford River. The brook trout density at FS1 in June 1985 was  $269 \pm 47.5$  trout per ha with biomass of 2.35 kg/ha. Most of these fish were

YOY and yearling fish with very low densities of adult fish. Trout densities at FCD were estimated at 60.7 fish/ha (biomass = 1.28 kg/ha) at pre-movement to 0 fish during the summer post-movement period. These densities are very low when compared to literature values and are probably indicative of the variable conditions of the Ford River. These data also indicate that a large percentage of the population moves out of the lower river (FCD site) in the spring movement period.

ELF calibration studies determined that the brook trout densities range from 0.0 fish/ha at FCD to 405.7 fish/ha at TM and that biomass ranges from 0.0 kg/ha at FCD to 14.7 kg/ha at TM. Overall values are below Michigan averages and show the recruitment is low at the sites sampled (except TM). Statistical analysis of the population characteristics will be reported in the 1989 report.

### 3. Brook Trout Age, Growth, and Condition

Age and growth analysis using scales indicated that the brook trout in the Ford River exhibit average or better growth when compared to literature values. Brook trout length at age 1 was approximately 90 mm, at age 2 was approximately 188 mm and at age 3 was approximately 285 mm. Statistical analysis of this data is in progress and will be reported in the next report. Brook trout condition was examined using relative weight condition factors ( $W_r$ ). A standard weight formula was calculated from 45 literature populations for use in this analysis. Ford River brook trout demonstrated average to below average condition when compared to the species average ( $W_r = 89 - 101$ ). Condition factors declined from 1983 to 1986 and improved in 1987 and 1988. Statistical analysis of this data is in progress and will be reported in the next report.

## VII. PROJECT RATIONALE AND APPROACH

Our research plan is directed at determining the effects of extremely low-level, long term electromagnetic fields (ELF) and gradients produced by the ELF Communications Systems on aquatic plant and animal life. The integrated approach we have taken is to combine the major interrelated and interactive components of aquatic systems (i.e., periphytic algae, aquatic insects, and fish) and to monitor sensitive life history events and community processes critical to the basic structure and function of stream ecosystems. These include: periphyton and stream invertebrate colonization, migration, diversity, trophic level changes in density and biomass, as well as primary productivity; organic matter processing by macroinvertebrates; dynamics of fish population growth, reproduction, and survival; fish behavior including movement patterns of homing and migration, and fish pathogen and parasite loads. Since many of these processes and events are mutually dependent on one another and interactions are complex, we feel that a holistic approach with a multi-disciplinary effort is imperative.

Our research plan represents an integrated study of stream ecosystems involving three aquatic components for monitoring the potential effects of ELF. These components are: (1) periphytic algae; 2) aquatic insects; and 3) fish. The design incorporates studies of ecosystem properties with studies of behavior and biology of individual species so that any effects of ELF can be quantified at the population, community and ecosystem levels.

We selected stream ecosystems as representative aquatic ecosystems rather than lakes or marshes because; (1) upstream-downstream paired plots on the same system provide less variability than between lake comparisons; (2) migratory behavior is more likely to be important in stream organisms; and (3) our expertise and interests are oriented toward stream ecology.

The effects of ELF on stream ecosystems will be tested using a paired plot design of selected sections of the chosen stream, the Ford River. Plots were selected to afford one area of study away from the antenna corridor for use as a control site (FCD), and another area directly under the antenna cable for use as the experimental site (FEX) (Fig. VII.1). These two stream sections constitute our paired plot design. We have intensively studied and sampled the river at these sites since June of 1983, when the final site selections were made. We also monitor fish movement using

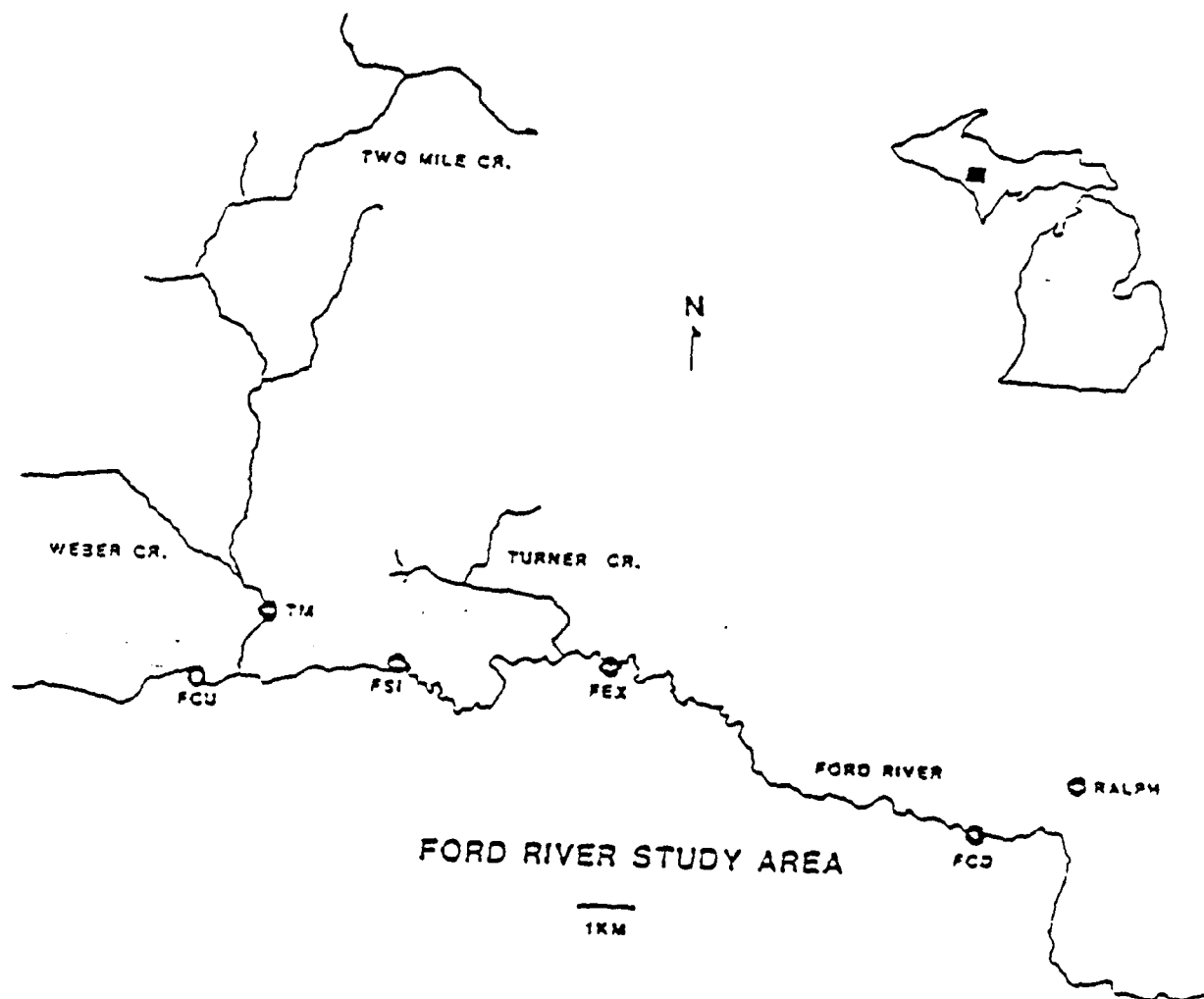


Figure VII. 1 Map of the Ford River study sites for the Aquatic Studies Group.

the other sites indicated on Fig. VII.1 (FS1, FCU, and TM).

For the two primary sites, we are continuously monitoring stream velocity and water depth so the discharge can be calculated. Water temperatures, dissolved oxygen, pH, and solar radiation at the surface and at the stream bottom are also being continuously monitored. We also sample all other chemical parameters required in the RFP.

The data generated from this research should; (1) determine whether the ELF Communications System affects aquatic plant and animal life in stream systems; and (2) contribute to a better understanding of stream processes which will help clarify a number of important aspects of current conceptual models of stream ecosystem structure and function.

## VIII. OVERALL OBJECTIVES AND SPECIFIC TASK OBJECTIVES

### OVERALL OBJECTIVE

Our major objective in this study is to determine the effects of low level, long term electromagnetic fields and gradients produced by the ELF Communication System on aquatic plant and animal life in streams. The study will incorporate studies of ecosystem properties with studies of behavior and biology of individual species so that any effects of ELF will be quantified at the population, community and ecosystem level.

### SPECIFIC TASK OBJECTIVES

#### A. Periphytic Algal Studies

The objectives of the periphytic algal studies are:

- (1) to quantify any changes in species diversity, algal density, and chlorophyll a that occur as a result of ELF electromagnetic fields;
- (2) to quantify any changes in primary productivity that might occur as a result of ELF; and
- (3) to monitor algal cell volume and chlorophyll a to phaeophytin a ratio, thereby providing an index to physiological stress of periphytic algal cells that might occur as a result of ELF electromagnetic fields.

#### B. Aquatic Insect Studies

The objectives of the studies of aquatic insects are:

- (1) to quantify any changes in organic matter processing rates that occur as a result of ELF;
- (2) to quantify changes in species richness, individual abundances, and species diversity of the aquatic insect communities associated with leaf packs and inorganic stream bottom substrates;
- (3) to quantify changes in upstream-downstream movements of selected aquatic insects that might occur as a result of ELF; and
- (4) to quantify trophic, behavioral, and community level changes in selected species of aquatic insects from an array of functional feeding groups (grazers, collectors, etc.).

#### C. Fish Studies

The objectives of the studies of fish are:

- (1) To quantify any changes in the seasonal movement patterns and abundance of the mobile fish community that occur as a result of ELF;
- (2) To quantify any changes in the rate of brook trout movement through the ELF coridor that occur as a result of ELF electromagnetic fields;
- (3) To quantify any changes in the rates of parasitism of one mobile species (longnose dace) and one sessile species (mottled sculpin) of fish that occur as a result of ELF.

## IX. PROGRESS BY WORK ELEMENT

### Element 1 - Conduct Ambient Monitoring Program

Changes from workplan - None.

#### Objectives

The objectives of this work element are: (1) to provide the background data on physical and chemical parameters needed to correlate observations on biological community dynamics with environmental parameters, and (2) to monitor stream chemistry to determine whether or not observed changes in community structure are related to water quality changes rather than potential ELF radiation induced changes.

#### Rationale

The chemical and physical factors selected for study are known or suspected to be important factors that may control or influence growth, community structure, or community dynamics of periphyton, insects, and fish. Correlating these variables with biological data may ultimately be useful in predicting the effects of these environmental parameters on the biotic community. Thus, they may be useful in separation of background environmental variability from effects induced by extremely low frequency electromagnetic radiation (ELF). Even though many of these variables may not presently correlate with biological data, unexpected large shifts could lead to dramatic changes in the biotic community. Thus, a second goal of the monitoring program is to document the presence or absence of shifts in chemical or physical variables that could occur if some perturbation such as an unexpected discharge of a pollutant were to occur. The physical and chemical parameters being monitored include the major plant nutrients because of their potential impact on trophic level dynamics (e.g. the various species of nitrogen and phosphorus as well as silica since diatoms dominate benthic algal production) or parameters that are known to influence insects and fish (e.g. turbidity, dissolved oxygen, discharge and current velocity, water temperature, etc.). Many of the parameters were originally specified in the request for proposal and offer general indices to site productivity or water quality (e.g. specific conductance, alkalinity, hardness, chloride, etc.). Some of the original parameters have been eliminated. These include total dissolved solids and suspended solids. Neither correlated well with biological parameters. Further, an index to total dissolved solids can be derived from correlations of this parameter with specific conductance, alkalinity, and hardness, while turbidity provides an index to suspended

solids (see correlations reported in the last annual report).

The goal of this annual report will be to present data on all parameters collected since 1983 at our current monitoring sites (the experimental site, FEX, and the control site, FCD) to document trends and variability in each parameter. We also present statistical comparisons between the two sites in order to document the fact that the two sites do not differ significantly for most of these parameters.

### Materials and Methods

Ambient monitoring stations were installed at the experimental site (FEX) and at the control site (FCD) in July, 1983 and were operated until the last week of October. Each year since 1983, these stations were installed in mid-April and were operated through the last week of October. This period represented the period from snow melt in spring until the time of some ice and snow deposition in autumn. After late October, problems were encountered with equipment maintenance and the stations were removed and stored for the winter.

The stations automatically logged on Omnidata data pods (model DP 211) the following parameters:

(1) Photosynthetically active solar radiation (PAR) was measured in a clearing on the stream bank and represented above water solar radiation. PAR was also measured under the water surface, 15 cm above the stream bottom in a riffle to pool transition area and represented below water solar radiation. These measurements were taken using Li-Cor Model LI-192SB underwater quantum sensors. Data were taken at both FEX and FCD through 1986, but measurements were deleted at FCD in 1987 due to failure of one of the data pods. No funds were in the budget for equipment replacement and this, coupled with the expected relative constancy of solar input between the two sites, led to the decision to cease measurement of solar radiation at one of the sites. This station was repaired for the 1988 season and data are again available for both sites.

(2) Dissolved oxygen was monitored using L. G. Nestor Model 8500 portable dissolved oxygen meters with general purpose submersible probes. These meters started to deteriorate in performance in 1987 after five years in the field. We had difficulty maintaining the meters and probes in operating condition especially at FCD. We had these meters repaired during the 1987-88 winter period and ordered new probes. We obtained reliable data for both sites for 1988.

(3) pH was measured using the Altex (Beckman) Monitor II System with specially built long term, gel-filled submersible pH probes from Fisher Scientific. These meters have given us



problems in the past. The meters were repaired over the winter of 1987-88 and new probes were ordered. We think that much of our past problems were associated with using the submersed probes for too long a period of time. These probes only have a submersed expected life of 3 or 4 months according to the chemist at Fisher Scientific. By changing the probes as needed over the summer, we were able to obtain consistent data during 1988. The pH values obtained from the ambient monitoring stations did not agree with paired laboratory derived pH values. There were consistent, small significant differences between the two (see results).

(4) Air and water temperature were monitored using thermistors.

Water depth was monitored using Stevens Type F strip chart recorders. These depth data were used to calculate discharge using a stage height-discharge relationship developed for each of the two sites on the Ford River. Stage (water level) - discharge relationships were determined for each station using Teledyne Gurley pygmy or Price-type current meters using the velocity area technique (Gregory and Walling 1973, p. 129) with at least 20 verticals per cross-section. At least 15 of these determinations have been made at various stage heights each season to insure that the relationship has not changed from previous years. The extremely low flow associated with the drought conditions in 1988 led to some adjustments of the stage-discharge relationship for the low discharge end of the regression for both sites. Discharge values were highly predictable from stage height data using calculated regressions with  $R^2$  values greater than 0.98 for FEX and 0.99 for FCD.

All automatically acquired data were checked and calibrated at least twice per week. Thus, even if the meters became inoperable, we still had at least two determinations per week for each parameter. For example, the field pH meters were calibrated twice per week with pH 7 and 10 buffers, and field pH meters were checked against an Orion Model 701 specific ion and pH meter in the laboratory at these same times twice each week. Dissolved oxygen meters were calibrated using the azide modification of the Winkler procedure (APHA 1980). Air and water temperature were recorded twice per week using hand-held thermometers, and depth was recorded from the manual staff gauges at each site.

Data from the data pods were transferred from the EPROM chips in the data pods to diskettes using an Omnidata Model 217 reader and an Apple II plus computer. Data, accumulated daily at 30 minute intervals, were read and summarized every

two weeks throughout the April to October period. These data are summarized for the 28 day intervals used for periphyton sampling in this report. Daily summary data were supplied to each task investigator (periphyton, insects, fish tasks) as computer printouts.

In addition to the manual determinations of pH, dissolved oxygen, water and air temperature as described above, samples were taken once per week for determination of turbidity, alkalinity, hardness, and specific conductance. These samples were chilled on ice, returned to the field laboratory, and the above parameters were determined within three hours of collection. Twice per week, samples were taken and frozen for later determination of total phosphorus, soluble reactive phosphorus (samples filtered within three hours of collection), nitrate-N, nitrite-N, ammonium-N, organic-N (total Kjeldahl N minus ammonium), chloride, and dissolved silicate-Si (Si samples were refrigerated instead of being frozen since freezing can cause interference with this procedure). The N, P, Si, and Cl samples were analyzed during the winter months after preparation of the annual report. Thus, there is a one year lag time in reporting these data. During winter months, samples were taken at one month intervals for all of the parameters discussed above through the winter of 1986-87. This interval was decreased to once every other month starting in 1987-88 since the expense of taking the samples is prohibitive given the minimal amount of biological data collected during the winter months.

All chemical analyses followed procedures outlined in Standard Methods (APHA 1980) or approved techniques of the U.S. Environmental Protection Agency (U.S. EPA 1979).

Stream velocity was also recorded for the periphyton samplers (see Element 2) using the Gurley pygmy meters about once per week. These data were used to adjust the positions of the periphyton samplers in the stream so that samplers at each site were exposed to comparable flow regimes. These velocity measurement will be presented in Element 2 of this report.

Statistical comparisons included paired t-tests between the two sites for each parameter, correlations between the two sites, and correlation matrix analyses of the relationships of these parameters to each other. Unless otherwise indicated, we accepted as significant  $p < 0.05$ .

## Results and Discussion

### A. Field Chemistry

The dissolved oxygen (DO) data for 1988 (Table 1.1) corroborated the highly predictable pattern observed at both sites for the first 4.5 years of the project with winter highs and summer lows (Fig. 1.1). In general, winter values were 11 mg/L or higher and summer values never dropped below 7 mg/L (Fig. 1.1). Since cold water contains more dissolved oxygen at saturation than does warm water, one would expect this type of pattern if the water in the river is near saturation throughout the year. The Ford River was typically 5-15 % undersaturated at each site, and DO was highly, negatively correlated with temperature at each site ( $r = -0.93$  and  $-0.95$  at FCD and FEX respectively,  $p < 0.01$  at both sites). Daily values of DO for 1988 at each site (Fig. 1.2) showed the expected relationship with temperature with decreases to lows in June, July, and August correlated with times of warmest water temperatures (Fig. 1.3) followed by increases in DO in the autumn (Fig. 1.2) as temperatures cooled (Fig. 1.3). There was a significant ( $p < 0.01$ ) correlation ( $r = 0.98$ ) in dissolved oxygen values between the two sites for 1988 (Table 1.2) as illustrated by Figs 1.1, 1.2, and Table 1.1. We also reported this high degree of correlation for all data collected prior to 1988 ( $r = 0.97$ ). In 1988, there were no significant differences between the two sites (Table 1.2) even though there had been significant differences ( $p < .001$ ) between the two sites for data collected prior to 1988 (see the 1987 annual report). These slight differences in the data collected prior to 1988 were probably related to the use of manually acquired data in these correlations and, to the fact, that we sampled FEX first on most days. The two hour travel time required for the research team to get from FEX to FCD resulted in warming of the stream prior to sampling FCD leading to these differences. In 1988, we sampled one site first on one date and the other was sampled first on the following date. This collection scheme resulted in no significant difference between sites. This lack of difference is supported by the daily mean values calculated from data taken every 30 minutes from the automatically acquired data (Fig. 1.2). When differences have occurred between the two sites in the past, they have been small (Fig. 1.1) with values at each site well above DO levels of 6.0 mg/L needed for maintenance of trout populations in good condition (Mckee and Wolf 1963).

The pH data for the two sites followed a pattern of summer highs and winter lows (Fig. 1.4, Table 1.1) probably

Table 1.1 pH and Dissolved Oxygen (mg/L) for the Ford River. Values are Means  $\pm$  S.E., N in Parentheses.

Date	Control Site (FCD)		Experimental Site (FEX)	
	pH	Dissolved Oxygen	pH	Dissolved Oxygen
10/26/87	7.92 $\pm$ 0.06 (9)	10.95 $\pm$ 0.37 (8)	7.92 $\pm$ 0.05 (9)	11.26 $\pm$ 0.39 (8)
12/27/87	7.80 (1)	12.75 (1)	7.70 (1)	12.35 (1)
2/27/88	7.55 (1)	10.90 (1)	7.60 (1)	11.00 (1)
5/16/88	7.95 $\pm$ 0.05 (7)	11.75 $\pm$ 0.39 (7)	7.96 $\pm$ 0.04 (7)	12.16 $\pm$ 0.43 (7)
6/13/88	8.03 $\pm$ 0.06 (8)	9.83 $\pm$ 0.27 (8)	7.92 $\pm$ 0.12 (8)	9.96 $\pm$ 0.33 (8)
7/11/88	8.19 $\pm$ 0.03 (8)	8.76 $\pm$ 0.18 (8)	8.22 $\pm$ 0.04 (8)	8.78 $\pm$ 0.23 (8)
8/8/88	8.16 $\pm$ 0.03 (8)	8.13 $\pm$ 0.20 (8)	8.23 $\pm$ 0.02 (8)	8.24 $\pm$ 0.13 (8)
9/6/88	8.04 $\pm$ 0.03 (7)	8.37 $\pm$ 0.25 (8)	8.10 $\pm$ 0.04 (7)	8.65 $\pm$ 0.29 (8)

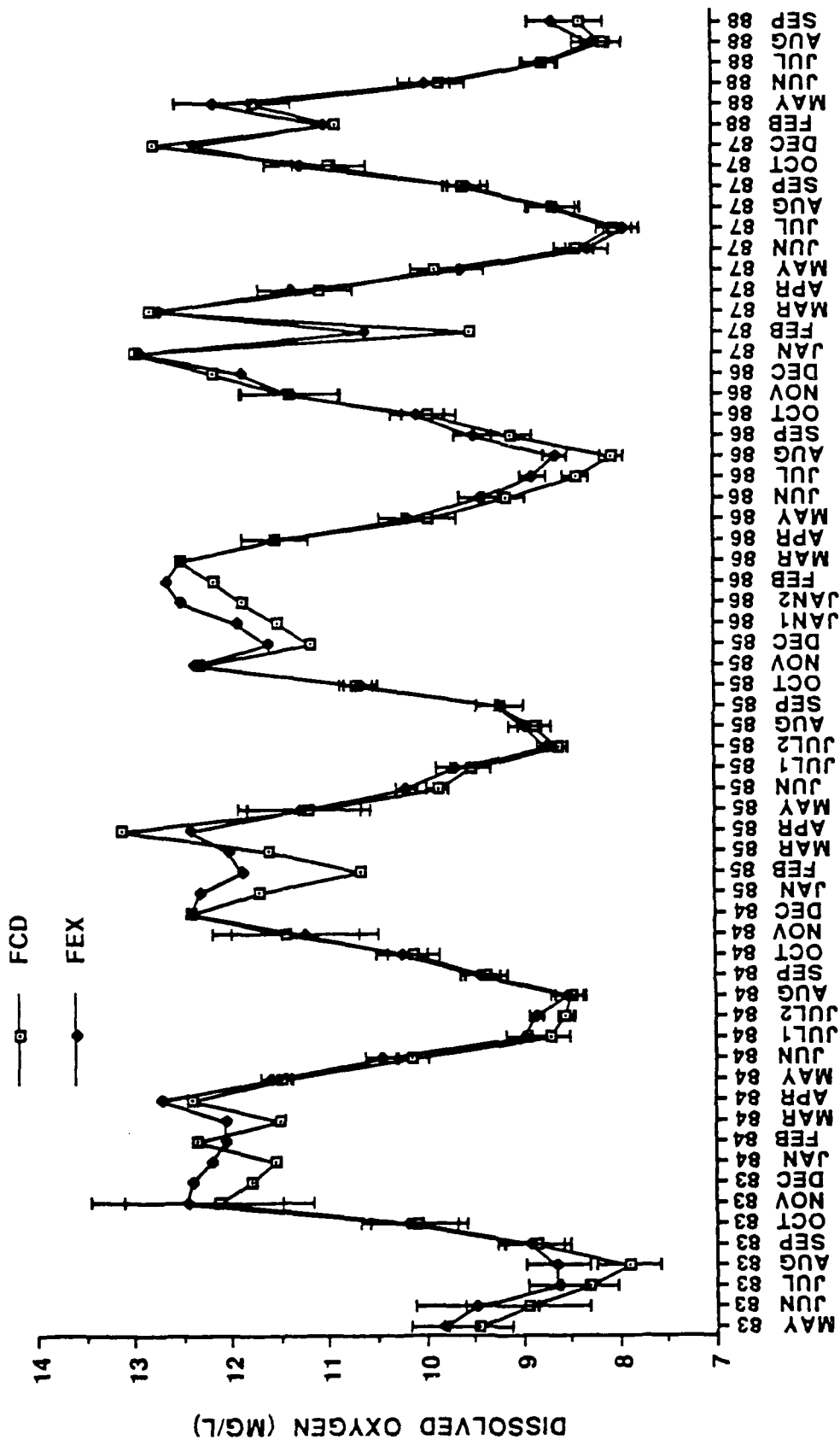


FIGURE 1.1 MEAN DISSOLVED OXYGEN LEVELS (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1988.

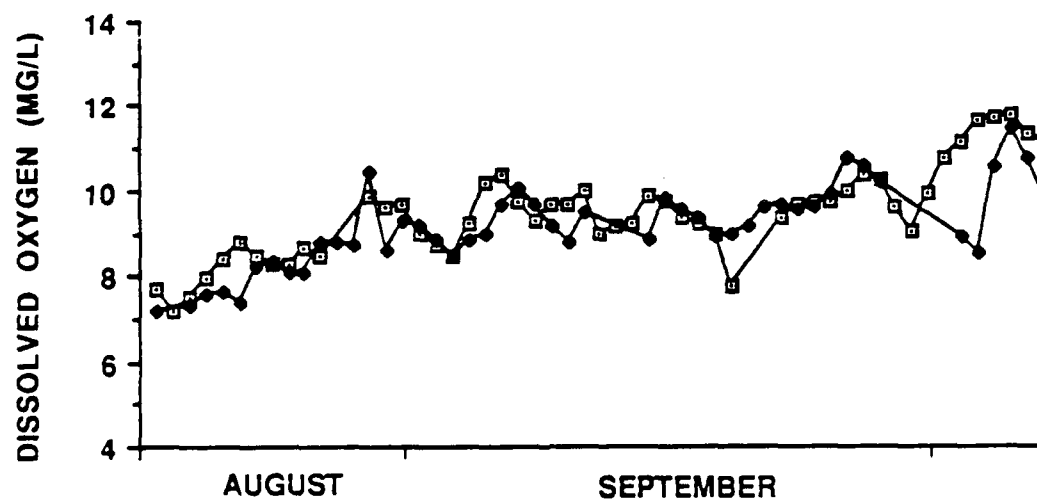
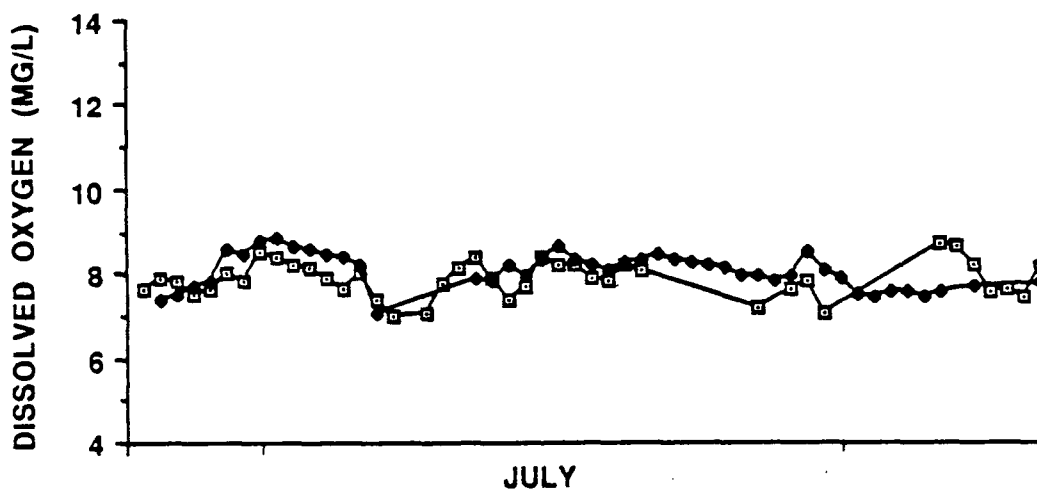
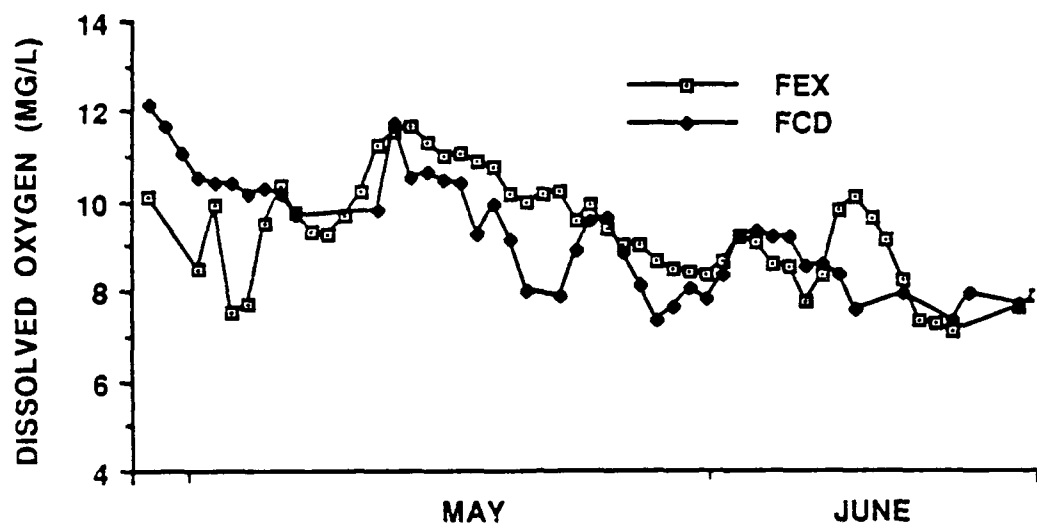


FIGURE 1.2 DAILY DISSOLVED OXYGEN MEANS FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES FOR 1988.

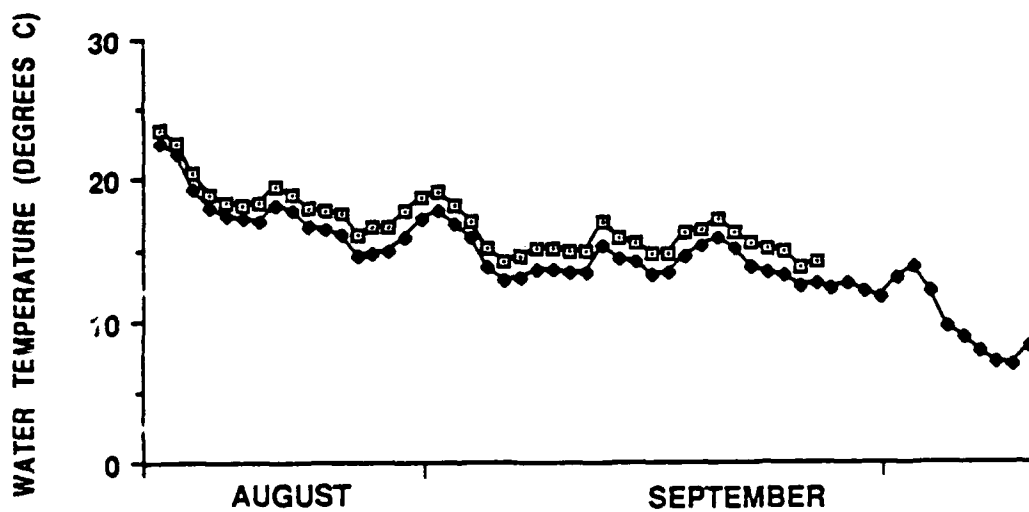
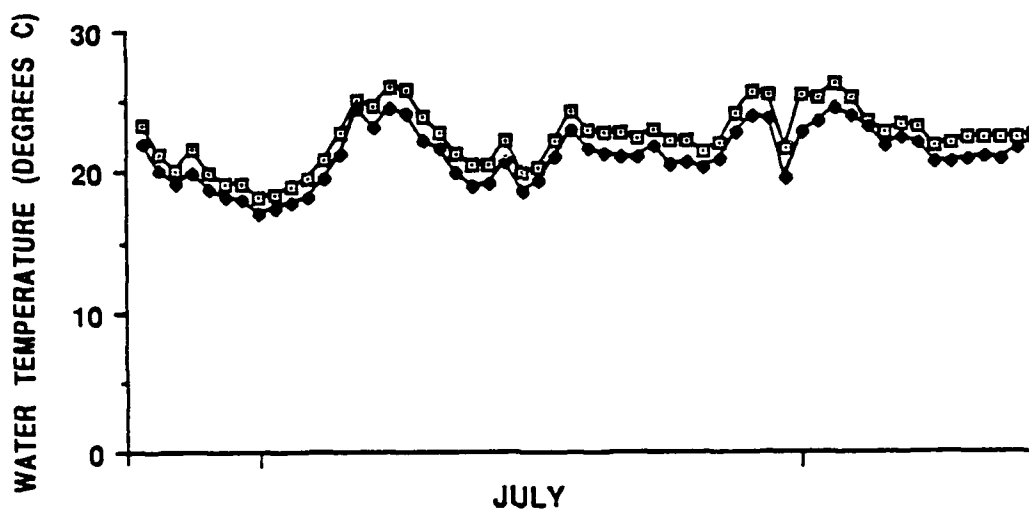
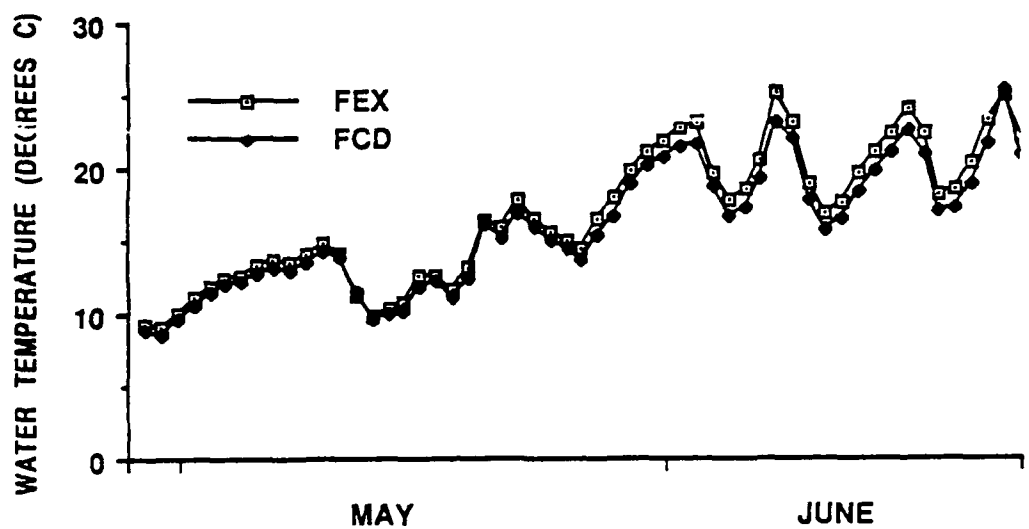


FIGURE 1.3 DAILY WATER TEMPERATURE MEANS FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES FOR 1988.

Table 1.2 Correlation coefficients and t-test Values (Paired-t)  
for Water Chemical Constituents and Ambient parameters  
Between Control (FCD) and Experimental (FEX) sites,  
N = 8.

Parameter	Correlation Coefficient	Paired t-value
Conductivity	.85**	1.871
Hardness	.99**	2.489*
Alkalinity	.99**	2.095
Turbidity	.98**	1.883
pH	.95**	-0.051
Dissolved Oxygen	.98**	-1.062
Water Temperature	.99**	-3.751**

\* p < 0.05

\*\* p < 0.01



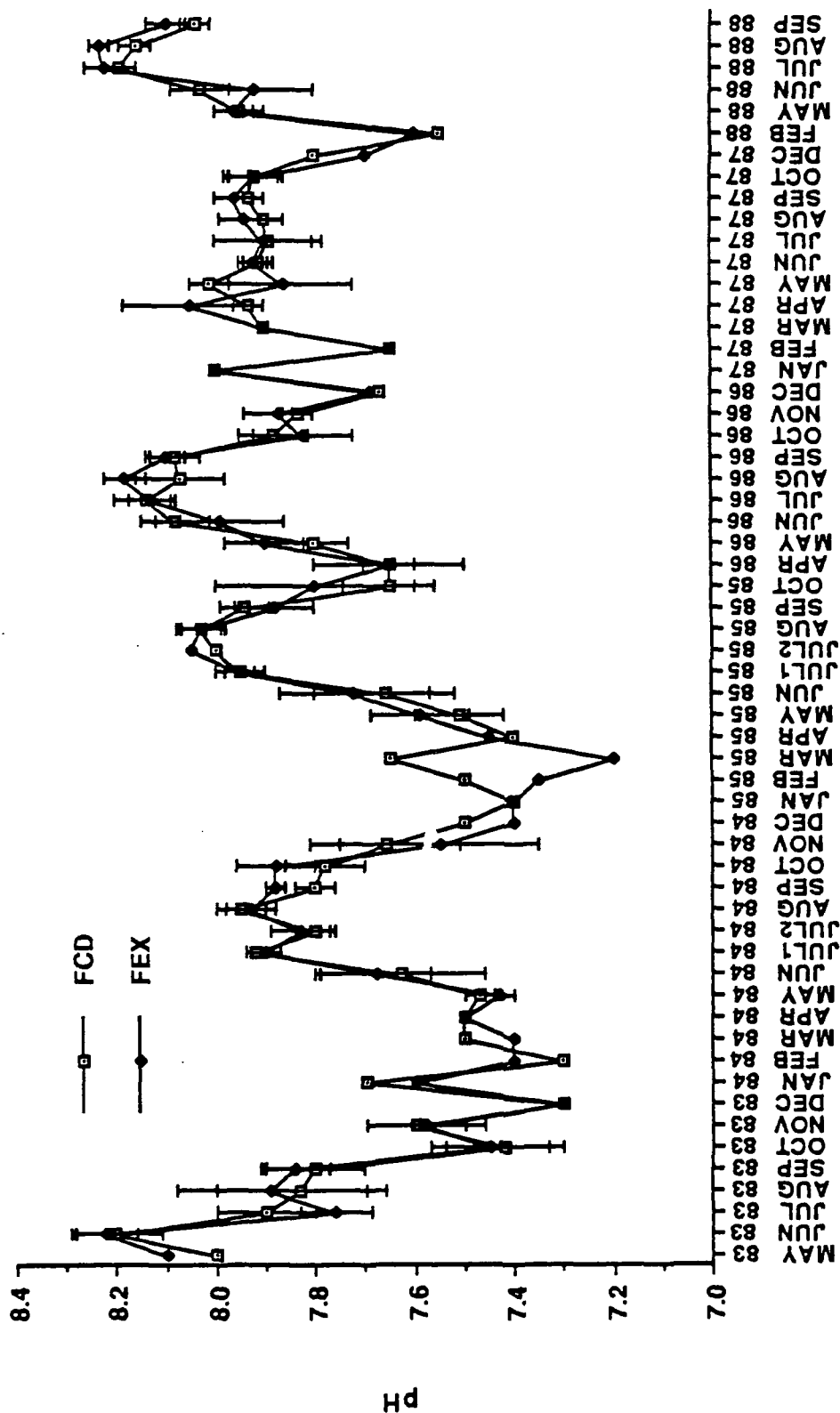


FIGURE 1.4 MEAN pH LEVELS (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1988.

related to higher levels of primary production in the summer (see Element 2) coupled with lower stream discharge, and higher values for alkalinity (pH was significantly ( $p < 0.05$ ) correlated with all these parameters). Because of the large number of samples taken since 1983, any  $r$  value greater than 0.3 is significant at the  $p < 0.05$  level for all of the water quality parameters. The most highly correlated parameters with pH were water temperature with  $r$ 's greater than 0.72 at both sites and discharge with  $r$ 's greater than -0.67 at both sites. The pH values at the two sites were significantly correlated with each other in 1988, and there were no significant differences between sites (Table 1.2) as was true for all data collected prior to 1988 (see the 1987 annual report). Automatically acquired data for the two sites for 1988 were consistent in quality unlike the poor quality of the data collected in 1986 and 1987. The changes in procedure described in the methods section resulted in this consistent data in 1988. However, the laboratory data and the field data for 1988 do not quite agree (Table 1.3). Thus, we contrasted these data by taking paired samples, recording data from newly calibrated field instruments and then determining pH in the laboratory on a sample collected at the same time. Paired  $t$  tests showed that there were significant differences ( $p < 0.01$ ) between the two data sets with the laboratory instrument recording pH values that were about 0.1 to 0.2 pH units higher than the field data. Thus, the data presented in Fig. 1.4 and Table 1.1 are data from the manual, twice per week determinations, since these data are available for the entire study period. We will continue to monitor pH with the datapod system, since such 24 hour data, along with DO and temperature data, may be potentially useful for community metabolism calculations.

Alkalinity and hardness followed similar trends for the two sites (Table 1.4. Figs. 1.5, 1.6) with high values occurring during times of low flows and low values occurring during times of high flows (Fig. 1.7, 1.8). Correlation coefficients support these observations with  $r$  values between discharge and either alkalinity or hardness greater than -0.84 at both sites for both parameters ( $p < 0.01$ ). These parameters are also significantly ( $p < 0.01$ ) positively correlated with specific conductance ( $r = 0.74$  or greater). As expected, hardness and alkalinity are highly correlated with each other ( $r = 0.96$ ,  $p < 0.01$ ) at both sites, and it would be feasible to drop one of these two analyses from our sampling program. If we elect to drop one of these two in the future, we will drop hardness. Alkalinity at FCD was highly correlated with alkalinity at FEX both in 1988

Table 1.3 A comparison of 28 day mean pH values obtained from water samples taken from the river and analyzed in the lab on an Orion meter and values obtained in the field from the Ambient monitoring pH meters. Data are means  $\pm$  S.E., N in parentheses.

Date	Ford Experimental (FEX)		Ford Control (FCD)	
	Lab pH	Field pH	Lab pH	Field pH
5/16/88	7.95 $\pm$ 0.05 (7)		7.96 $\pm$ 0.04 (7)	8.02 $\pm$ 0.02 (28)
6/13/88	8.03 $\pm$ 0.06 (8)	8.21 $\pm$ 0.04 (28)	7.92 $\pm$ 0.12 (8)	7.93 $\pm$ 0.06 (28)
7/11/88	8.19 $\pm$ 0.03 (8)	8.10 $\pm$ 0.03 (28)	8.22 $\pm$ 0.04 (8)	8.15 $\pm$ 0.01 (28)
8/8/88	8.16 $\pm$ 0.03 (8)	8.07 $\pm$ 0.04 (28)	8.23 $\pm$ 0.02 (8)	8.04 $\pm$ 0.03 (28)
9/6/88	8.04 $\pm$ 0.03 (7)	7.94 $\pm$ 0.03 (28)	8.10 $\pm$ 0.04 (7)	7.86 $\pm$ 0.05 (28)

Table 1.4 Alkalinity and Hardness (mg CaCO<sub>3</sub>/L) for the Ford River. Values are Means  
± S.E., N in Parentheses.

Date	Control Site (FCD)		Experimental Site (FEX)	
	Hardness	Alkalinity	Hardness	Alkalinity
10/26/87	164 ± 6 (4)	149 ± 6 (5)	162 ± 6 (4)	146 ± 6 (5)
12/27/87	166 (1)	138 (1)	164 (1)	137 (1)
2/27/88	188 (1)	163 (1)	185 (1)	161 (1)
5/16/88	136 ± 2 (5)	113 ± 4 (5)	132 ± 3 (5)	107 ± 4 (5)
6/13/88	153 ± 11 (4)	138 ± 12 (4)	150 ± 10 (4)	135 ± 12 (4)
7/11/88	184 ± 1 (4)	171 ± 1 (4)	185 ± 4 (4)	172 ± 4 (4)
8/8/88	184 ± 2 (4)	169 ± 3 (3)	185 ± 1 (4)	171 ± 2 (4)
9/6/88	160 ± 4 (4)	137 ± 5 (4)	159 ± 3 (4)	134 ± 6 (4)

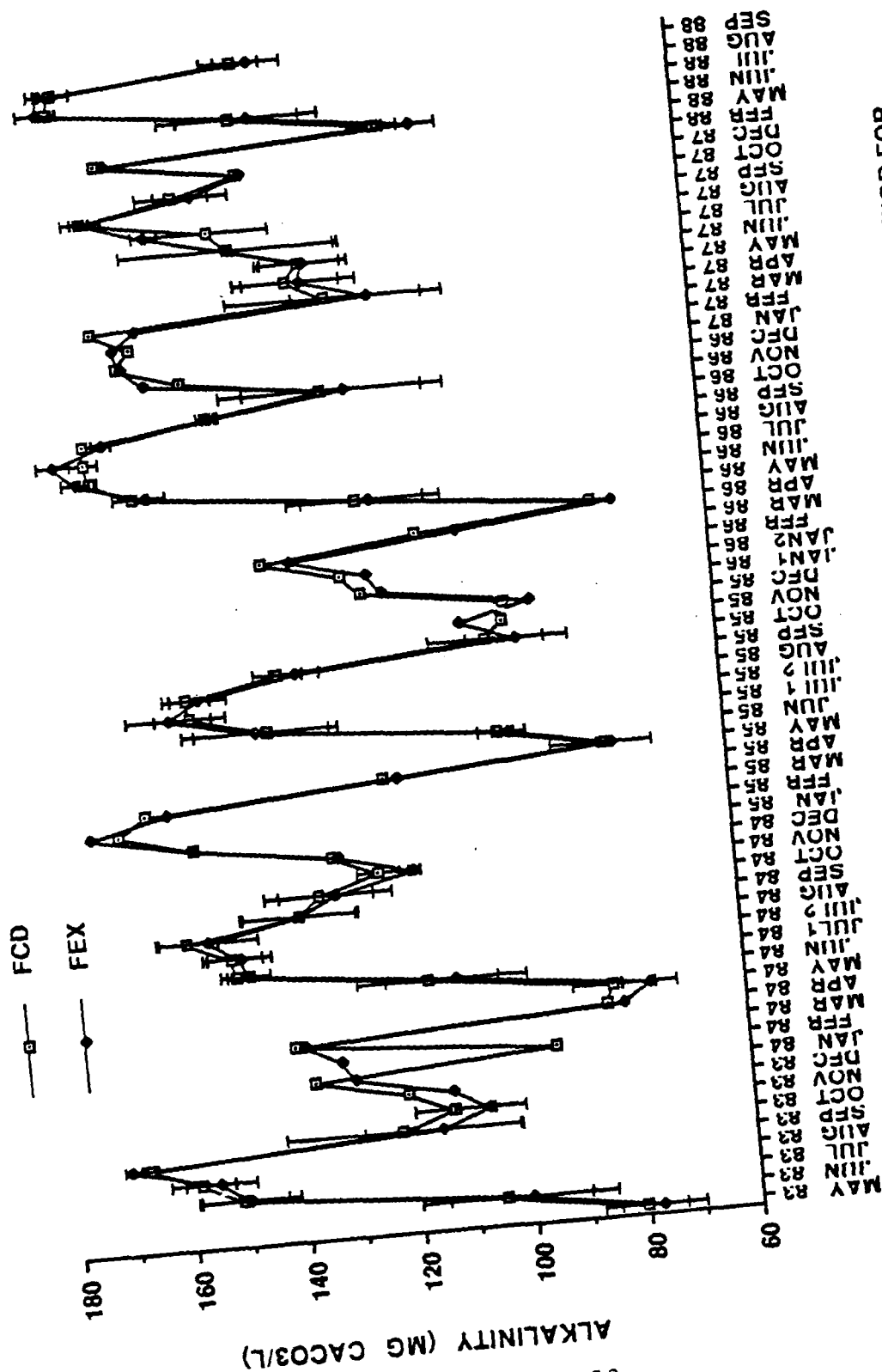


FIGURE 1.5 MEAN ALKALINITY LEVELS (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1988.

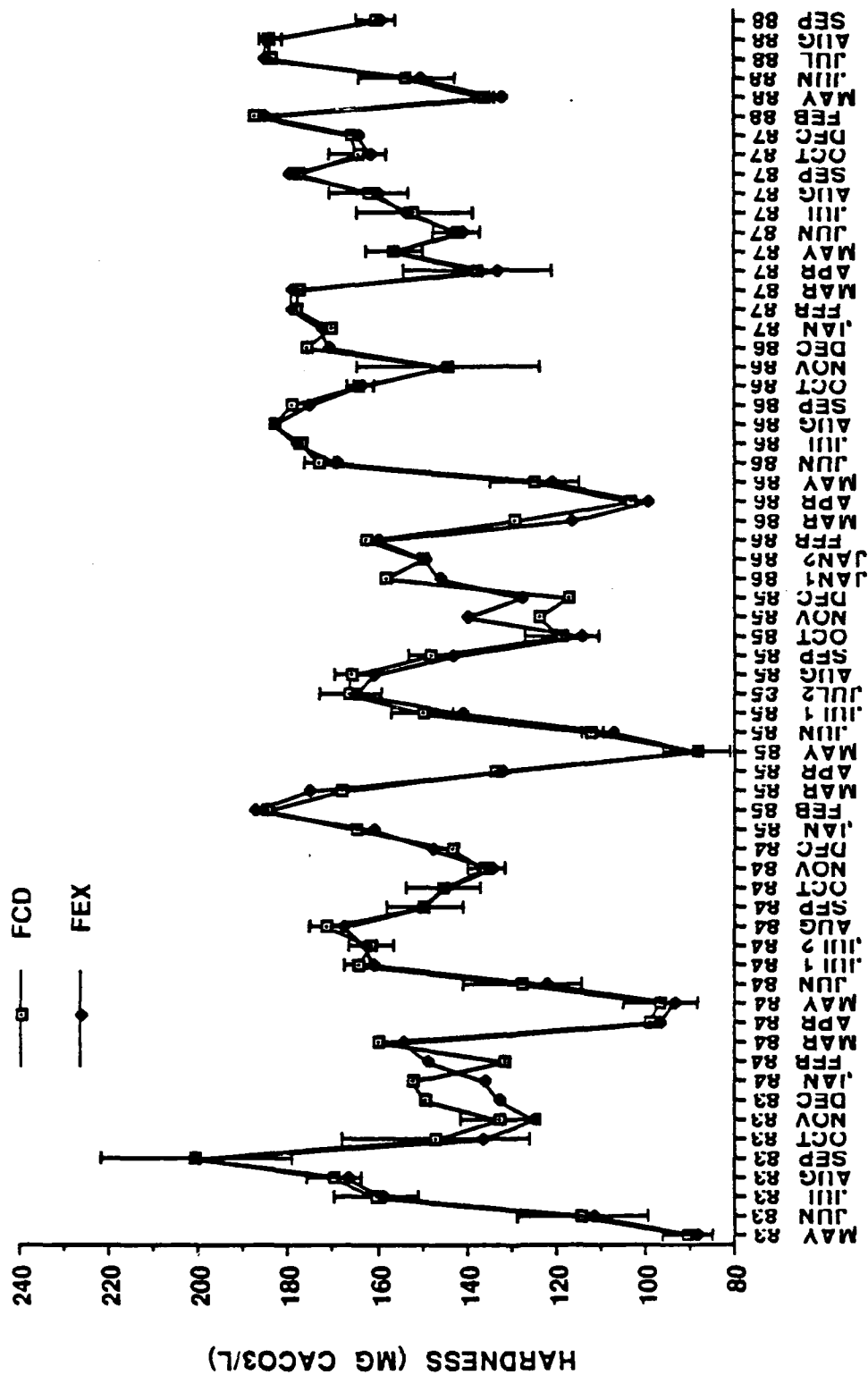


FIGURE 1.6 MEAN HARDNESS LEVELS (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1988.



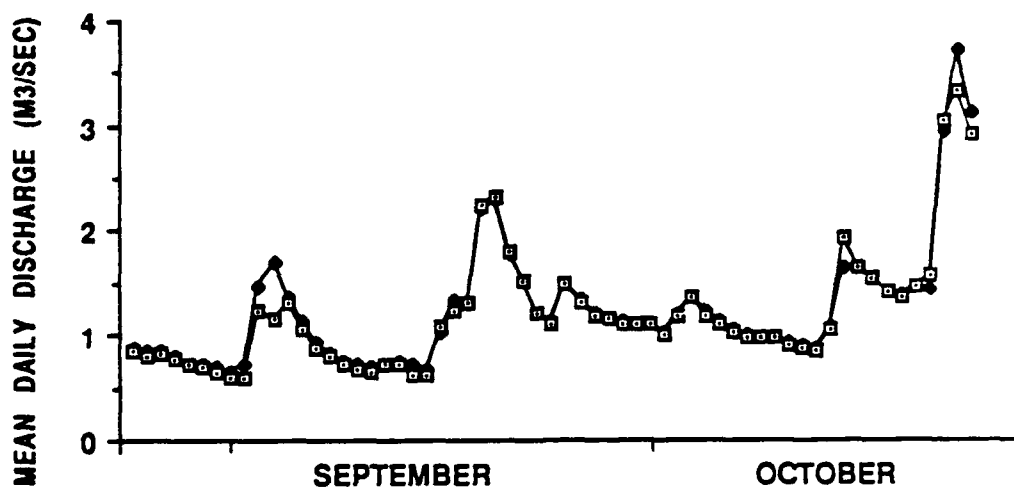
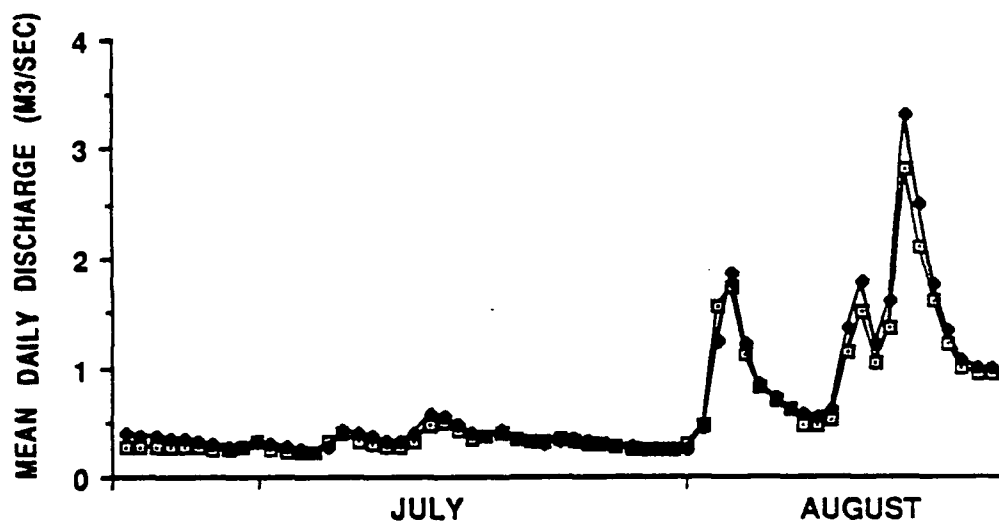
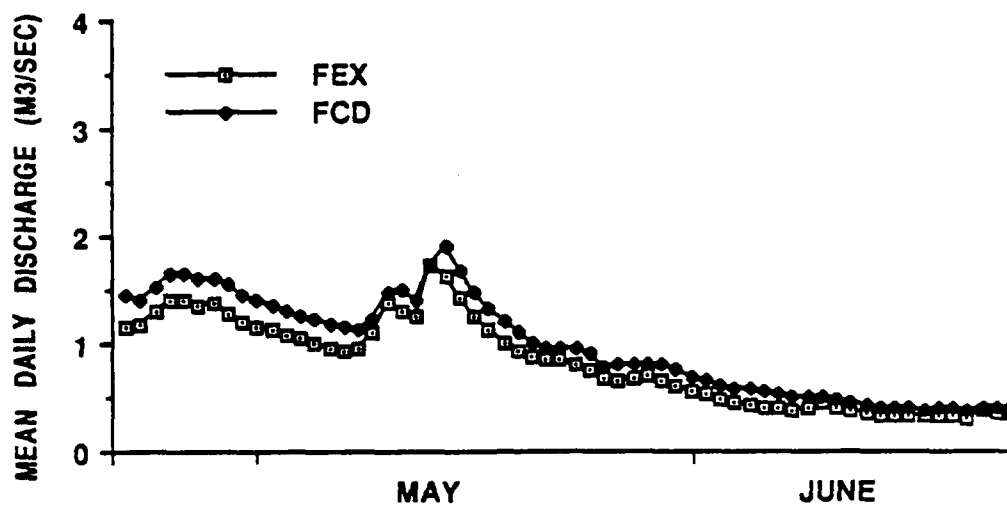


FIGURE 1.8 DAILY DISCHARGE MEANS FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES FOR 1988.



( $r=0.99$ ,  $p<0.01$ ) and when all data since 1983 are included ( $r=0.97$ ,  $p<0.01$ ), there was no significant difference between the sites (Table 1.2). Hardness was just as highly correlated between the sites, but there was a significant difference between the sites (Table 1.2). Hardness at FCD was slightly, but significantly, greater than at FEX. This increase may be related to the expected increase in cations in a downstream direction.

Conductivity is significantly ( $p<0.05$ ) negatively correlated with discharge at both sites ( $r = -0.77$  and  $-0.80$  at FEX and FCD respectively) and positively correlated with both alkalinity and hardness at both sites ( $r = 0.74$  or greater). Thus, the pattern for conductivity (Fig. 1.9, Table 1.5) is very similar to the patterns exhibited by alkalinity and hardness (Figs. 1.5, 1.6). Conductivity values at FEX were highly correlated ( $p<0.01$ ) with conductivity values at FCD during 1988 (Table 1.2) and for all data collected since 1983 ( $r=0.82$ ). There were no significant differences between sites (Table 1.2).

Suspended solids were dropped from the monitoring in 1988. Previously, turbidity (Table 1.5, Fig. 1.10) and suspended solids were significantly correlated ( $r=0.64$  and  $0.75$ ,  $p<0.05$  at FEX and FCD respectively) and were always relatively low reflecting the excellent water quality of the Ford River. Suspended solids analyses were time consuming and did not correlate strongly with biological parameters. They were always well below the 30 mg/L that trout are known to tolerate with no problem (McKee and Wolf 1963). The correlation of suspended solids with turbidity will enable us to detect any potential problems from upstream erosion linked to construction or other such activities should they occur in the future by simply monitoring turbidity. Thus, we deleted suspended solids from our work plan in 1988. Turbidity at FEX was highly correlated with turbidity at FCD, and there were no significant differences between the two sites (Table 1.2). Turbidity was significantly correlated with discharge at both sites ( $r=0.44$ ,  $p<0.01$ ).

#### B. Nutrient Chemistry

Nutrient chemistry samples are frozen and analyzed during the following winter. Thus, data in this annual report do not include data for 1988.

Trends in total phosphorus prior to 1987 were not obvious because of high variability of this constituent (Fig. 1.11),

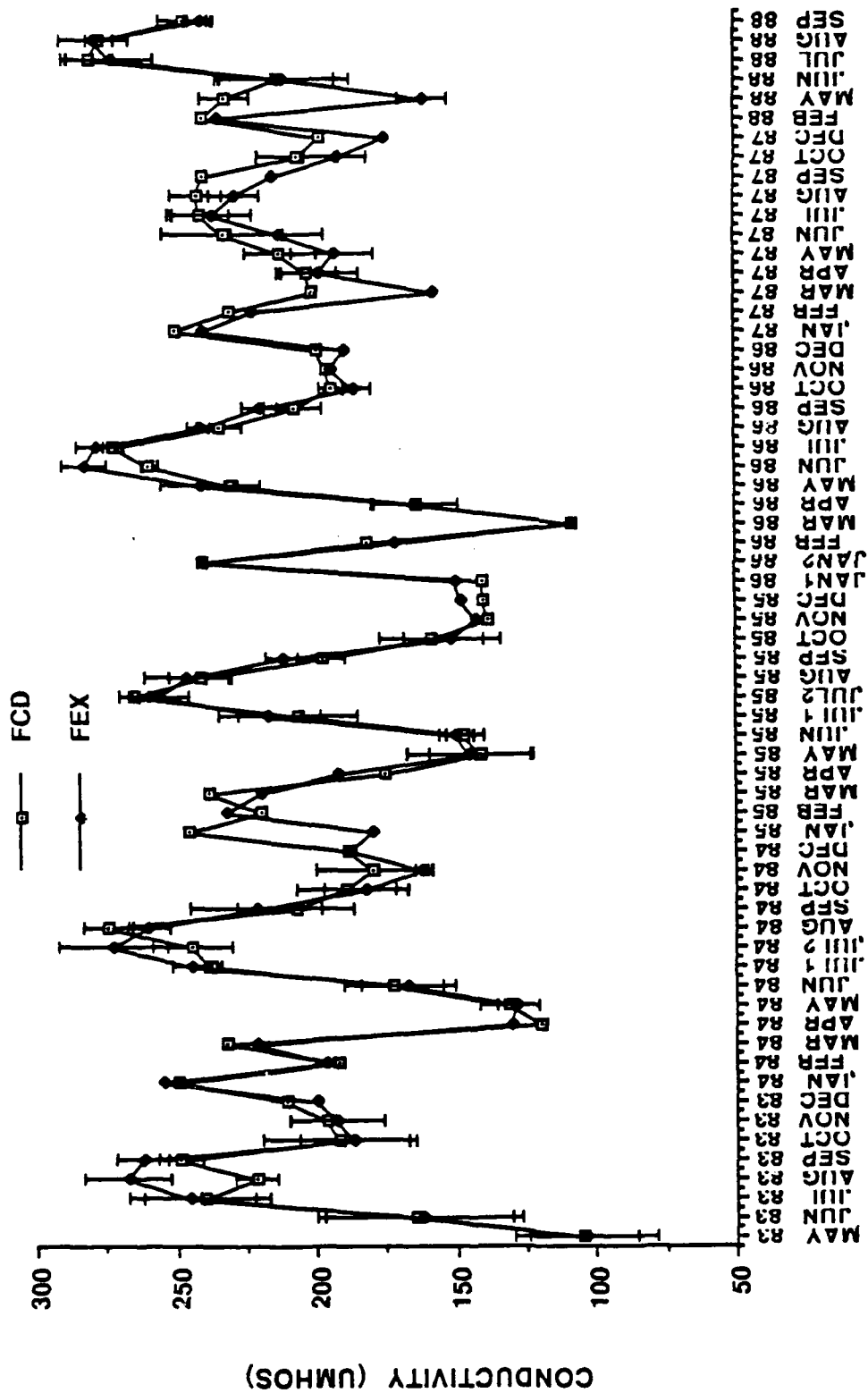


FIGURE 1.9 MEAN CONDUCTIVITY LEVELS ( $\pm$ S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1988.

Table 1.5 Conductivity (umhos/cm) and Turbidity (NTU'S) for the Ford River.  
Values are Means  $\pm$  S.E., N in Parentheses.

Date	Control Site (FCD)		Experimental Site (FEX)	
	Conductivity	Turbidity	Conductivity	Turbidity
10/26/87	206 $\pm$ 15 (4)	0.7 $\pm$ 0.1 (8)	193 $\pm$ 11 (4)	0.6 $\pm$ 0.1 (8)
12/27/87	198 (1)	1.0 (1)	175 (1)	1.0 (1)
2/27/88	240 (1)	1.5 (1)	235 (1)	1.2 (1)
5/16/88	232 $\pm$ 9 (5)	0.92 $\pm$ (5)	161 $\pm$ 9 (5)	0.8 $\pm$ 0.1 (5)
6/13/88	213 $\pm$ 20 (4)	1.2 $\pm$ 0.2 (4)	211 $\pm$ 24 (4)	1.0 $\pm$ 0.1 (4)
7/11/88	280 $\pm$ 9 (4)	1.7 $\pm$ 0.2 (4)	273 $\pm$ 16 (4)	1.65 $\pm$ 0.2 (4)
8/8/88	277 $\pm$ 5 (4)	1.4 $\pm$ 0.1 (4)	279 $\pm$ 12 (4)	1.4 $\pm$ 0.1 (4)
9/6/88	247 $\pm$ 9 (4)	2.2 $\pm$ 0.3 (4)	241 $\pm$ 5 (4)	2.3 $\pm$ 0.1 (4)

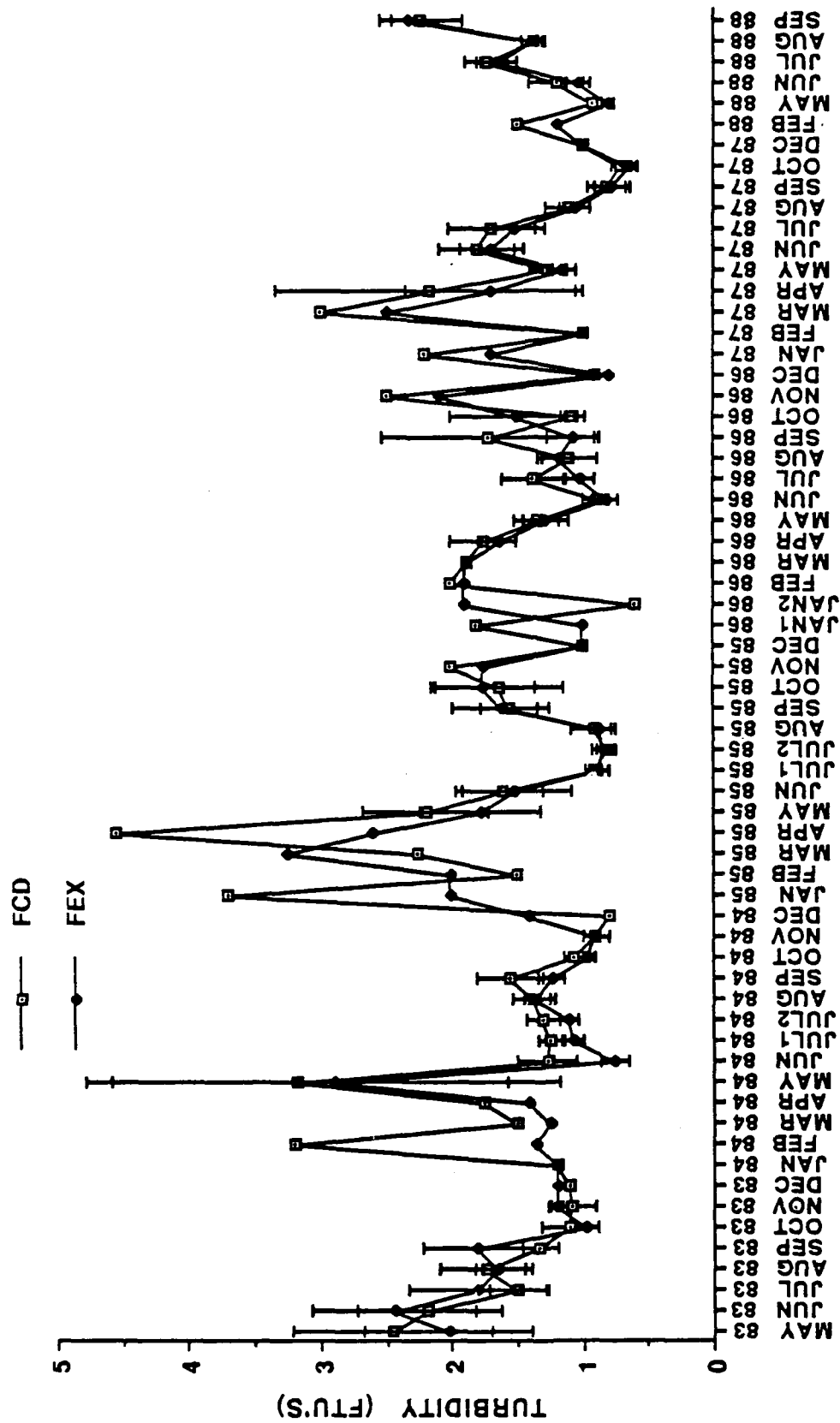


FIGURE 1.10 MEAN TURBIDITY LEVELS (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1988.

Table 1.6 Soluble Reactive Phosphorus (ug P/l) and Total Phosphorus (ug P/l) for the Ford River for 1987. Values are Means  $\pm$  S.E., N in parentheses.

Dates	Experimental Site (FEX)			Control Site (FCD)		
	Soluble Reactive P	Total P		Soluble Reactive P	Total P	
1/9/87		15.00	(1)	3.00	(1)	23 (1)
2/6/87		10.00	(1)			
3/6/87	3.00	(1) 71.00	(1)	2.00	(1)	
4/30/87	4.00	(2) 16.00 $\pm$ 1.41	(2)	4.00	(2)	10 (2)
5/26/87	3.67 $\pm$ 0.71	(6) 28.14 $\pm$ 4.49	(7)	4.00 $\pm$ 1.09	(7)	30.14 $\pm$ 8.02 (7)
6/22/87	4.75 $\pm$ 0.41	(8) 34.12 $\pm$ 2.61	(8)	4.63 $\pm$ 0.53	(8)	31.88 $\pm$ 2.12 (8)
7/20/87	4.12 $\pm$ 0.45	(9) 36.67 $\pm$ 7.12	(9)	3.78 $\pm$ 0.36	(9)	38.22 $\pm$ 6.24 (9)
8/31/87	3.63 $\pm$ 0.50	(8) 28.00 $\pm$ 1.84	(8)	4.00 $\pm$ 1.16	(8)	30.12 $\pm$ 2.56 (8)
9/28/87	7.50 $\pm$ 0.89	(8) 34.00 $\pm$ 4.58	(8)	7.38 $\pm$ 1.41	(8)	33.75 $\pm$ 3.64 (8)
10/26/87	5.75 $\pm$ 0.61	(9) 25.11 $\pm$ 2.84	(9)	6.67 $\pm$ 0.82	(9)	24.11 $\pm$ 5.02 (9)
12/27/87	5.00	(1) 22.00	(1)	4.00	(1)	26.00 (1)

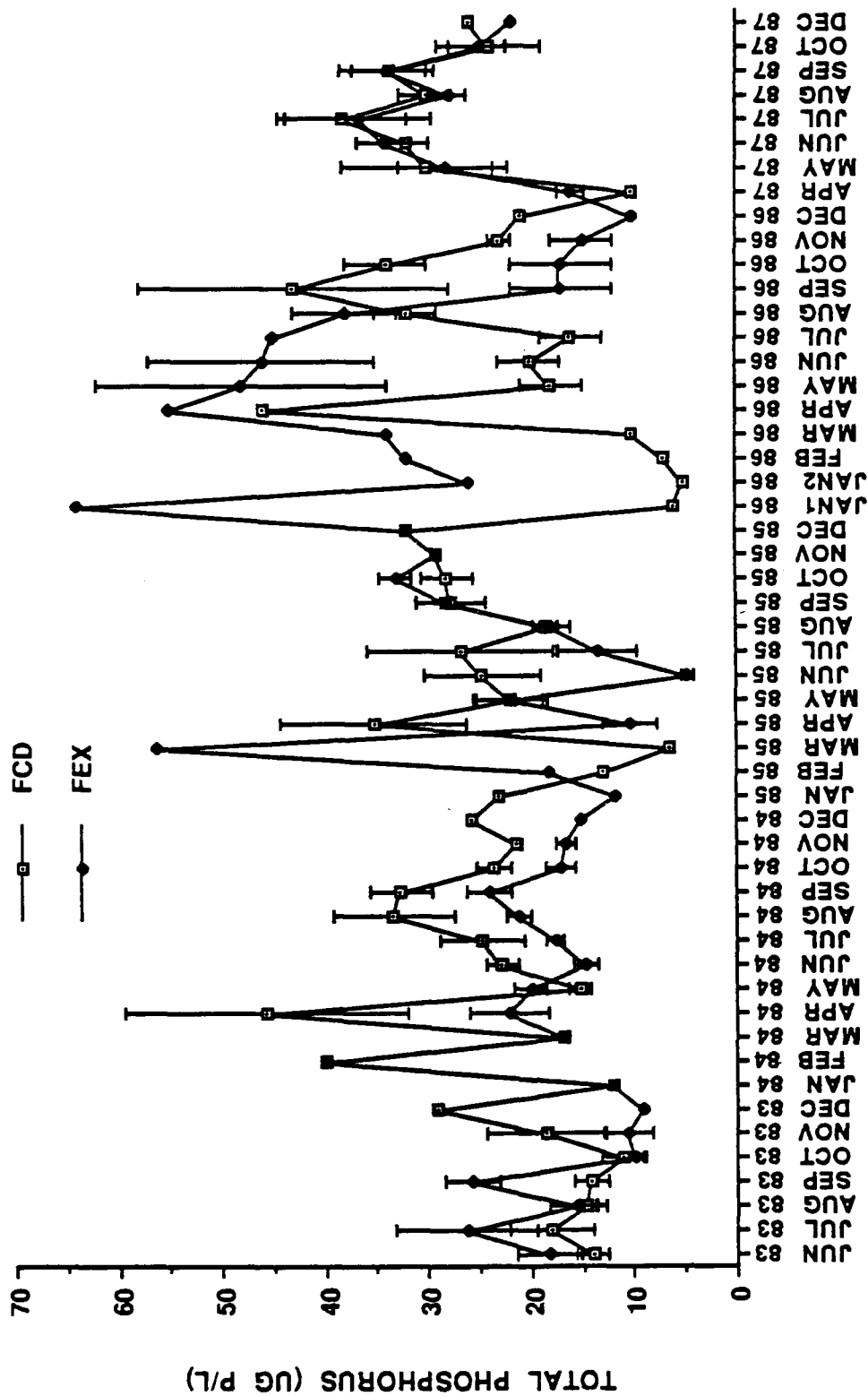


FIGURE 1.11 MEAN TOTAL PHOSPHORUS CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1988.

although values appeared to be somewhat higher in the winter, spring, and summer in 1986 at FEX than they were in previous years. The data for 1987 (Table 1.6, Fig. 1.11) were much more consistent between sites than had previously been the case. We have no explanation for this increase in consistency. However, the average values for 1987 are about what they were prior to 1986 (Fig. 1.11). The concentrations of total P in the Ford River were characteristic of values for the eastern U.S. reflecting land use that is 50 to 90 % forest (Omernik 1977 placed Michigan in the eastern U.S. region). Land use in the Ford River watershed is dominated by short rotation forestry with Populus tremuloides (quaking aspen) being the predominant forest species. Total P at FEX was significantly correlated with total P at FCD in 1987 (Table 1.7), although this had not been the case in previous years. There were no significant differences between the two sites in 1987 continuing the trend reported for the data from 1983 through 1986 (see the 1987 annual report). Total P was positively correlated with organic N ( $r=0.45$  for FEX and  $0.37$  for FCD) and negatively correlated with Si ( $r = -0.34$  and  $-0.38$  for FEX and FCD) ( $p<0.05$ ). These correlations were not very robust but are reasonable since both total P and organic N are primarily associated with particulates which is usually directly correlated with discharge while Si is usually inversely correlated with discharge.

Soluble reactive phosphorus (SRP) consistently stayed below  $10 \mu\text{g P/L}$  except at FCD in late 1986 (Fig. 1.12, Table 1.6). There did appear to be an increase at FCD in 1986 that did not occur at FEX (Fig. 1.12), but this apparent trend towards increased P at the control site did not continue in 1987. In fact, there was no significant difference in SRP between FCD and FEX in 1987, and SRP at FCD was highly correlated with SRP at FEX (Table 1.7). Even prior to 1987, there was no overall significant difference between FEX and FCD, and SRP at FEX was significantly correlated with SRP at FCD. The SRP values for FEX and FCD (Fig. 1.12, Table 1.6) were characteristic of values for land that is 50 to 90 % forested according to Omernik (1977). The only other chemical constituents that SRP was significantly correlated with included Cl and pH ( $p<0.05$ ).

Nitrate-N, nitrite-N, and ammonium-N values were usually comparable at both FEX and FCD (Figs. 1.13, 1.14, 1.15, Table 1.8). However, there was a divergence in nitrate-N values between the two sites in 1985 (Fig. 1.13), but nitrate-N was comparable for other time periods. One possibility for this difference is that leaching occurred from a small area of

Table 1.7 Results of Paired t-tests and correlations on Nutrient Chemistry Parameters for 1987 between the Control (FCD) and Experimental (FEX) sites.

Parameter	Paired t value	df	Probability	Correlation Coefficient (r)	Probability
Organic Nitrogen	-0.022	8	NS	.97	p < .01
Inorganic Nitrogen	0.129	8	NS	.97	p < .01
Ammonium-N	1.613	8	NS	.03	NS
Nitrate-N	-1.516	8	NS	.99	p < .01
Nitrite-N	-0.603	8	NS	.96	p < .01
Total Phosphorus	0.688	8	NS	.88	p < .01
Soluble Reactive-P	-0.511	8	NS	.93	p < .01
Silicate-Si	0.188	11	NS	.83	p < .01
Chloride	-2.160	9	NS	.85	p < .01



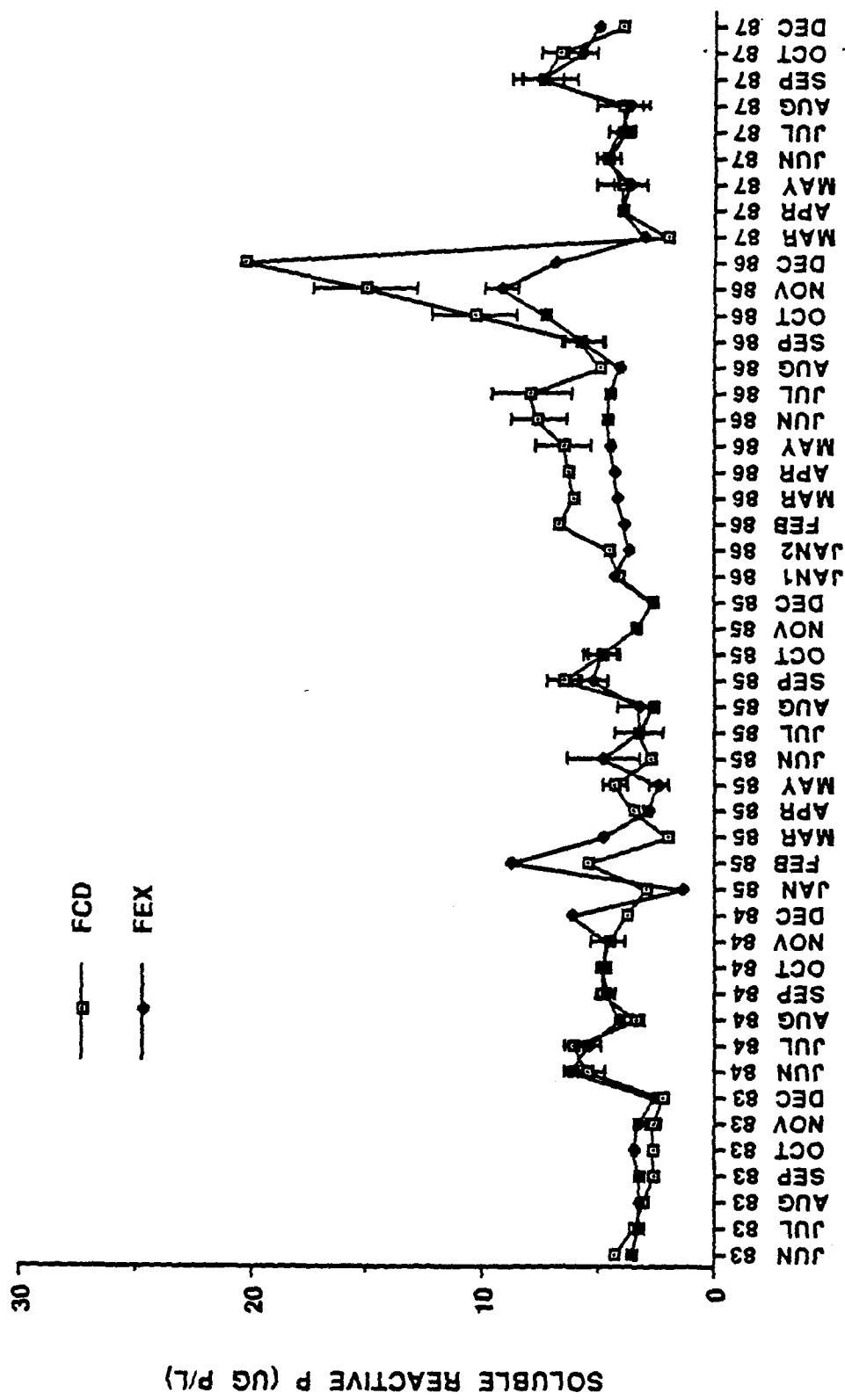


FIGURE 1.12 MEAN SOLUBLE REACTIVE PHOSPHORUS CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1987.

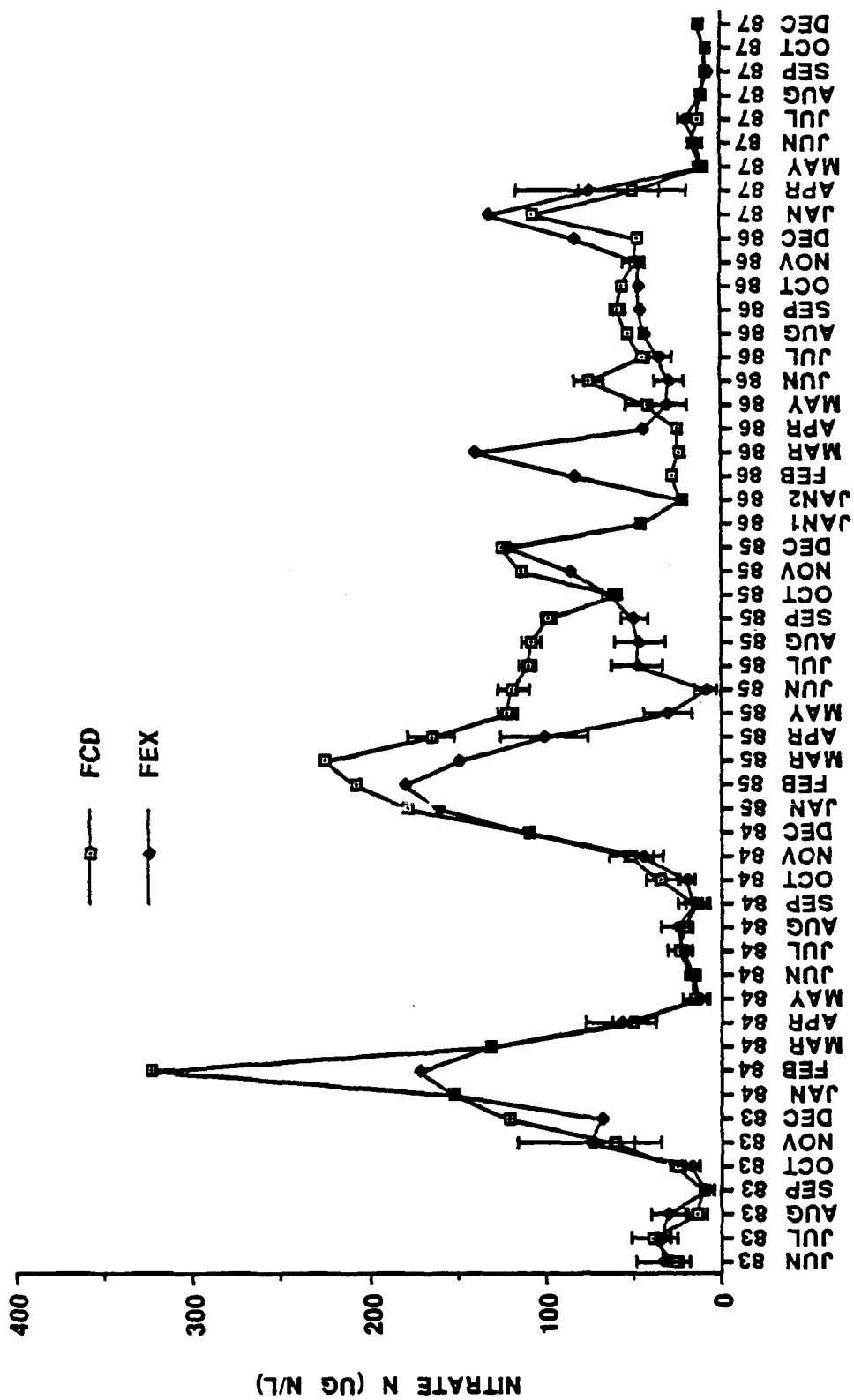


FIGURE 1.13 MEAN NITRATE-N CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1987.

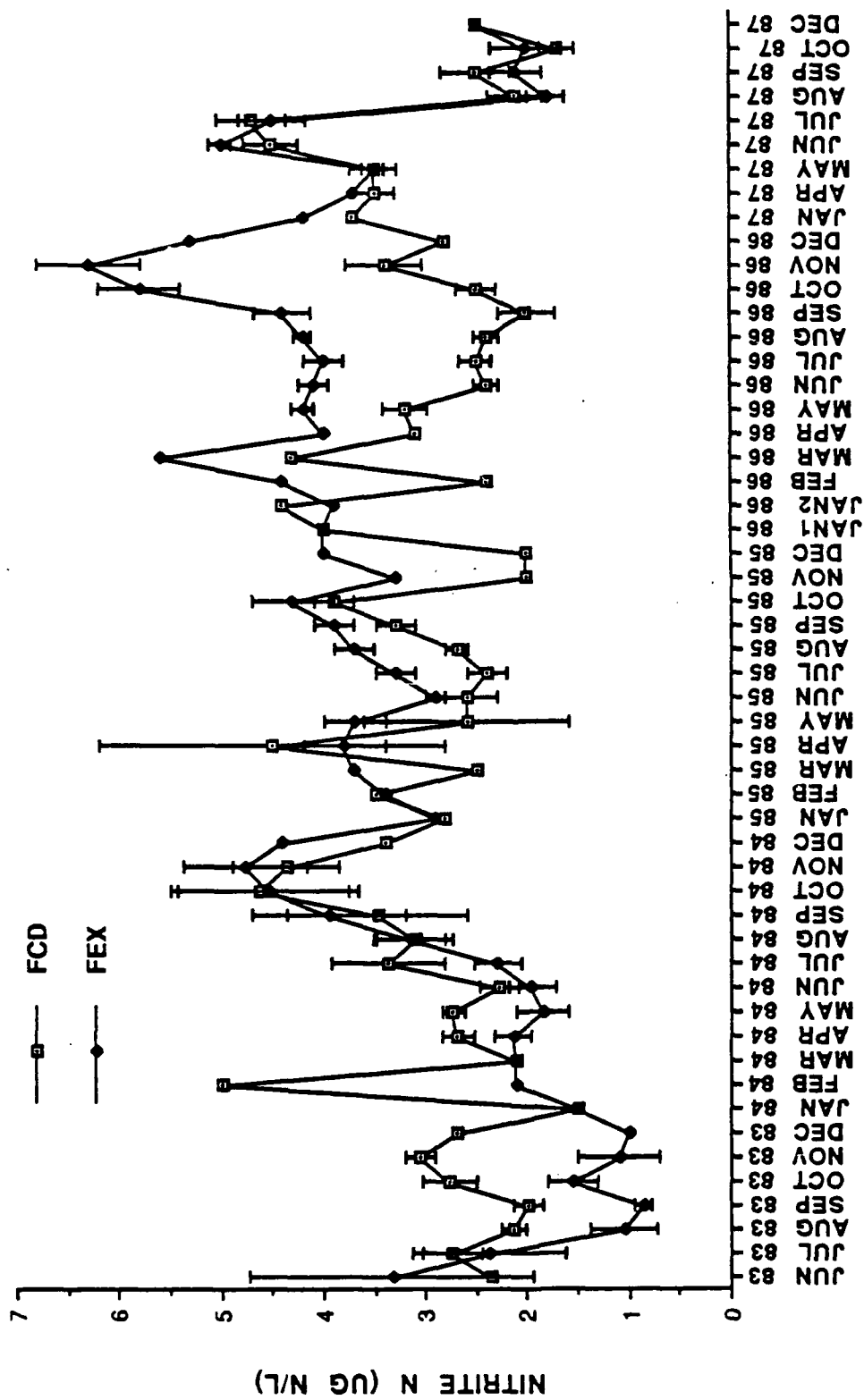


FIGURE 1.14 MEAN NITRITE-N CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1987.

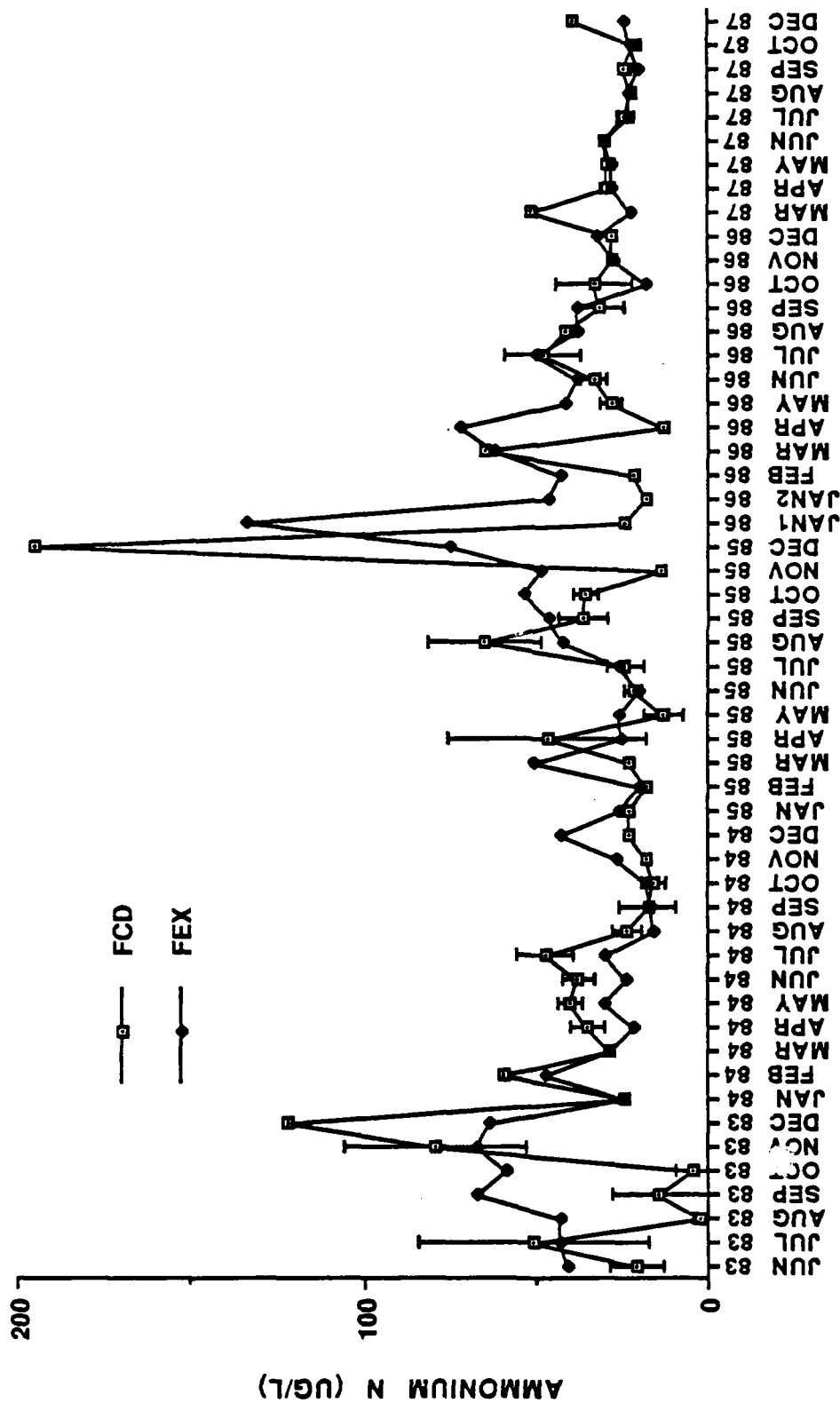


FIGURE 1.15 MEAN AMMONIUM CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD  
FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1987.

Table 1.8 Ammonium (ug N/L), Nitrate-N (ug N/L), and Nitrite-N (ug N/L) for the Ford River for 1987. Values are Means  $\pm$  S.E., N in parentheses.

Experimental Site (FEX)					
Date	Ammonium-N	Nitrate-N	Nitrite-N		
1/9/87	22	(1)	132	(1)	4.2
2/6/87	33 $\pm$ 11	(2)			3.95 $\pm$ 0.25
3/6/87	40 $\pm$ 4.5	(2)			3.7 $\pm$ 0
4/30/87	28 $\pm$ 2.0	(2)	75 $\pm$ 41	(2)	3.7 $\pm$ 0
5/26/87	28 $\pm$ 1.4	(6)	9 $\pm$ 2	(7)	3.5 $\pm$ 0.22
6/22/87	30 $\pm$ 1.4	(8)	13 $\pm$ 3	(8)	5.0 $\pm$ 0.11
7/20/87	23 $\pm$ 1.4	(9)	19 $\pm$ 4	(9)	4.5 $\pm$ 0.33
8/31/87	23 $\pm$ 1.1	(8)	11 $\pm$ 1	(8)	1.8 $\pm$ 0.18
9/28/87	20 $\pm$ 1.9	(8)	7 $\pm$ 1	(8)	2.1 $\pm$ 0.26
10/26/87	22 $\pm$ 1.6	(9)	8 $\pm$ 1	(9)	2.0 $\pm$ 0.34
12/27/87	24	(1)	12	(1)	2.5
Control Site (FCD)					
1/9/87	51	(1)	107	(1)	3.7
2/6/87					
3/6/87					
4/30/87	29 $\pm$ 2.1	(2)	50 $\pm$ 30	(2)	3.5 $\pm$ 0.20
5/26/87	29 $\pm$ 1.8	(7)	11 $\pm$ 4	(7)	3.5 $\pm$ 0.12
6/22/87	30 $\pm$ 0.8	(8)	15 $\pm$ 2	(8)	4.5 $\pm$ 0.26
7/20/87	24 $\pm$ 2.4	(9)	13 $\pm$ 2	(9)	4.7 $\pm$ 0.35
8/31/87	22 $\pm$ 1.5	(8)	11 $\pm$ 1	(8)	2.1 $\pm$ 0.27
9/28/87	24 $\pm$ 1.8	(8)	8 $\pm$ 1	(8)	2.5 $\pm$ 0.34
10/26/87	21 $\pm$ 1.7	(9)	8 $\pm$ 1	(9)	1.7 $\pm$ 0.17
12/27/87	39	(1)	12	(1)	2.5

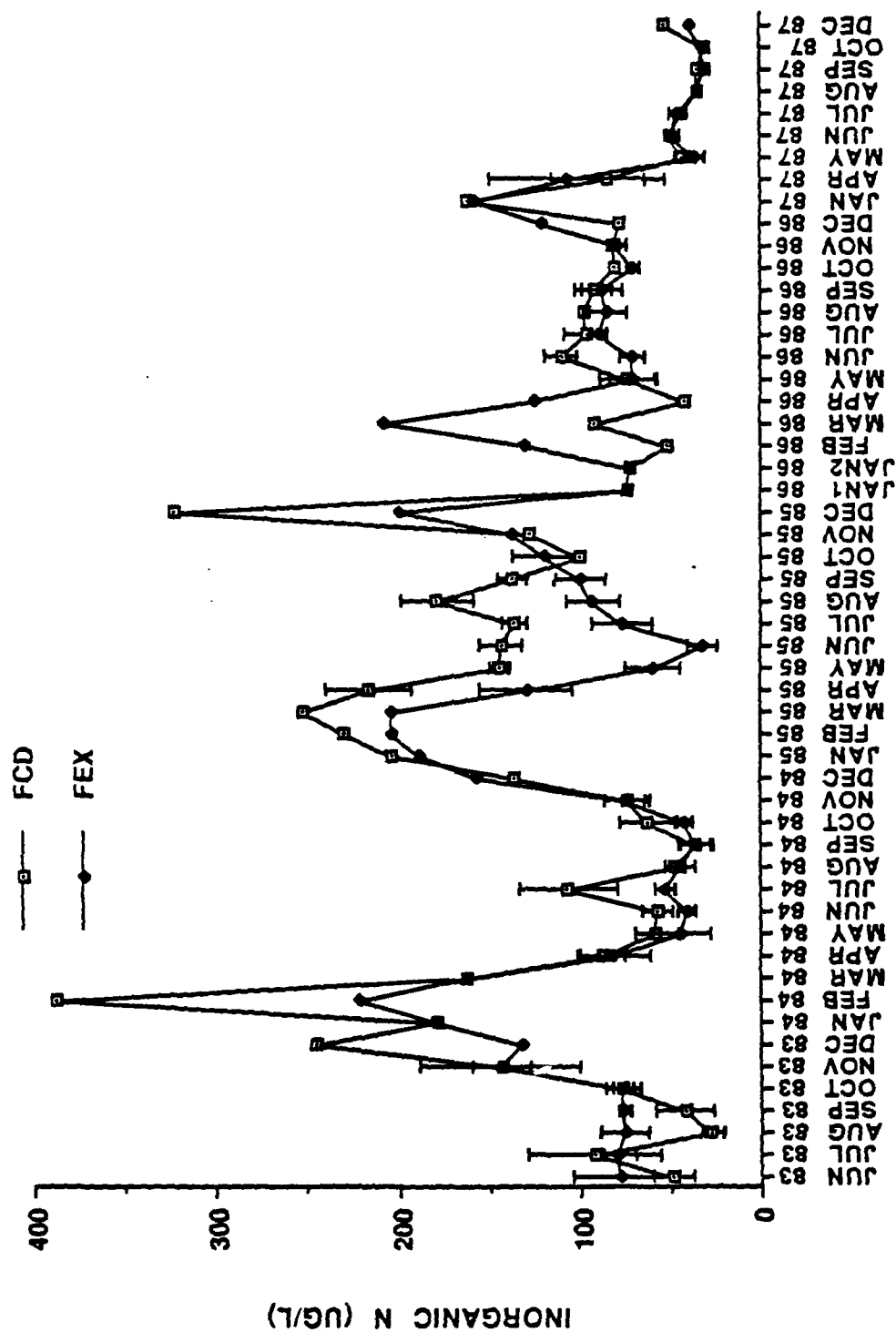


FIGURE 1.16 MEAN INORGANIC NITROGEN CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1987.

Table 1.9 Organic-N ( $\mu\text{g N/l}$ ) and Inorganic-N ( $\mu\text{gN/l}$ ) for the Ford River for 1987. Values are Means  $\pm$  S.E., N in parentheses.

Dates	Experimental Site (FEX)		Control Site (FCD)	
	Organic Nitrogen	Inorganic Nitrogen	Organic Nitrogen	Inorganic Nitrogen
1/9/87	248.0 (1)	158.2 (1)	529.0 (1)	161.7 (1)
2/6/87	155.5 $\pm$ 92.5 (2)	102.9 $\pm$ 55.3 (2)		
3/6/87	239.0 $\pm$ 176 (2)	86.4 $\pm$ 4.5 (2)		
4/30/87	312.0 $\pm$ 26 (2)	106.2 $\pm$ 42.5 (2)	119.0 $\pm$ 51 (2)	84.0 $\pm$ 30.7 (2)
5/26/87	417.3 $\pm$ 22.4 (7)	35.7 $\pm$ 5.1 (7)	467.1 $\pm$ 98.7 (7)	43.3 $\pm$ 4.7 (7)
6/22/87	796.5 $\pm$ 43.8 (8)	48.1 $\pm$ 3.7 (8)	815.9 $\pm$ 48.2 (8)	49.7 $\pm$ 2.7 (8)
7/20/87	751.6 $\pm$ 36.1 (9)	46.1 $\pm$ 3.9 (9)	733.4 $\pm$ 55.4 (9)	42.5 $\pm$ 2.7 (9)
8/31/87	1567.4 $\pm$ 62.9 (8)	34.9 $\pm$ 1.8 (8)	1441.6 $\pm$ 44.9 (8)	34.9 $\pm$ 1.7 (8)
9/28/87	1807.4 $\pm$ 92.1 (8)	29.6 $\pm$ 1.9 (8)	1871.4 $\pm$ 213.1 (8)	34.0 $\pm$ 1.9 (2)
10/26/87	1455.0 $\pm$ 162.2 (9)	32.4 $\pm$ 1.8 (9)	1473.6 $\pm$ 188.6 (9)	30.6 $\pm$ 1.8 (9)
12/27/87	806.0 (1)	38.7 (1)	701.0 (1)	53.1 (1)

forest just upstream of FCD that was clearcut in 1985. This forest practice is known to lead to high nitrate losses in the first year or so after cutting for some northern hardwoods forests similar to the forests along the Ford River (Bormann and Likens 1979, Vitousek et al. 1982). In order to better document the effect of watershed changes on nutrient losses in the future, we will attempt to locate aerial photos of the watershed taken over the sampling period and present them in future reports. Nitrate is the predominant form of inorganic nitrogen present in the Ford River. Thus, calculation of inorganic-N from the three components (Figs. 1.13, 1.14, 1.15) results in trends for inorganic-N very similar to those for nitrate-N (Fig. 1.16, Table 1.9). In fact, inorganic-N and nitrate-N are highly correlated ( $r=0.93$  or higher for both sites). The patterns for inorganic-N and nitrate-N generally follow the pattern of mid-summer lows and winter highs described for nitrate for northern hardwood forests by Bormann and Likens (1979). These values are characteristic of values for streams in the eastern U. S. that are 50 to 90 % forested (Omernik 1977).

Inorganic-N values were not significantly different between the two sites (Table 1.7). Concentrations of inorganic-N and nitrate-N at FEX were significantly correlated to concentrations at FCD (Table 1.7). Even though nitrate-N values were significantly correlated between FEX and FCD, there was a significant difference between the two sites prior to 1987. This significant difference may have been related to the increase in nitrate-N at FCD in 1985 already discussed above. There were no significant differences between the two sites for either nitrite or ammonium, and correlation coefficients between the two sites were low for these two parameters prior to 1987. In 1987, these trends continued except that nitrite was highly correlated between the sites (Table 1.7). Both inorganic-N and nitrate-N were significantly, positively correlated with dissolved oxygen and turbidity and negatively correlated with water temperature.

Organic nitrogen at FEX was significantly different from organic-N at FCD prior to 1987, but these differences disappeared in 1987 (Fig. 1.17, Table 1.9). As was true for inorganic-N, total P, and SRP values, organic-N values were characteristic of streams draining areas of the eastern U. S. that are 50 to 90 % forested (Omernik 1977).

There were no significant differences for silicate-Si between FEX and FCD (Tables 1.7, 1.10, Fig. 1.18), and



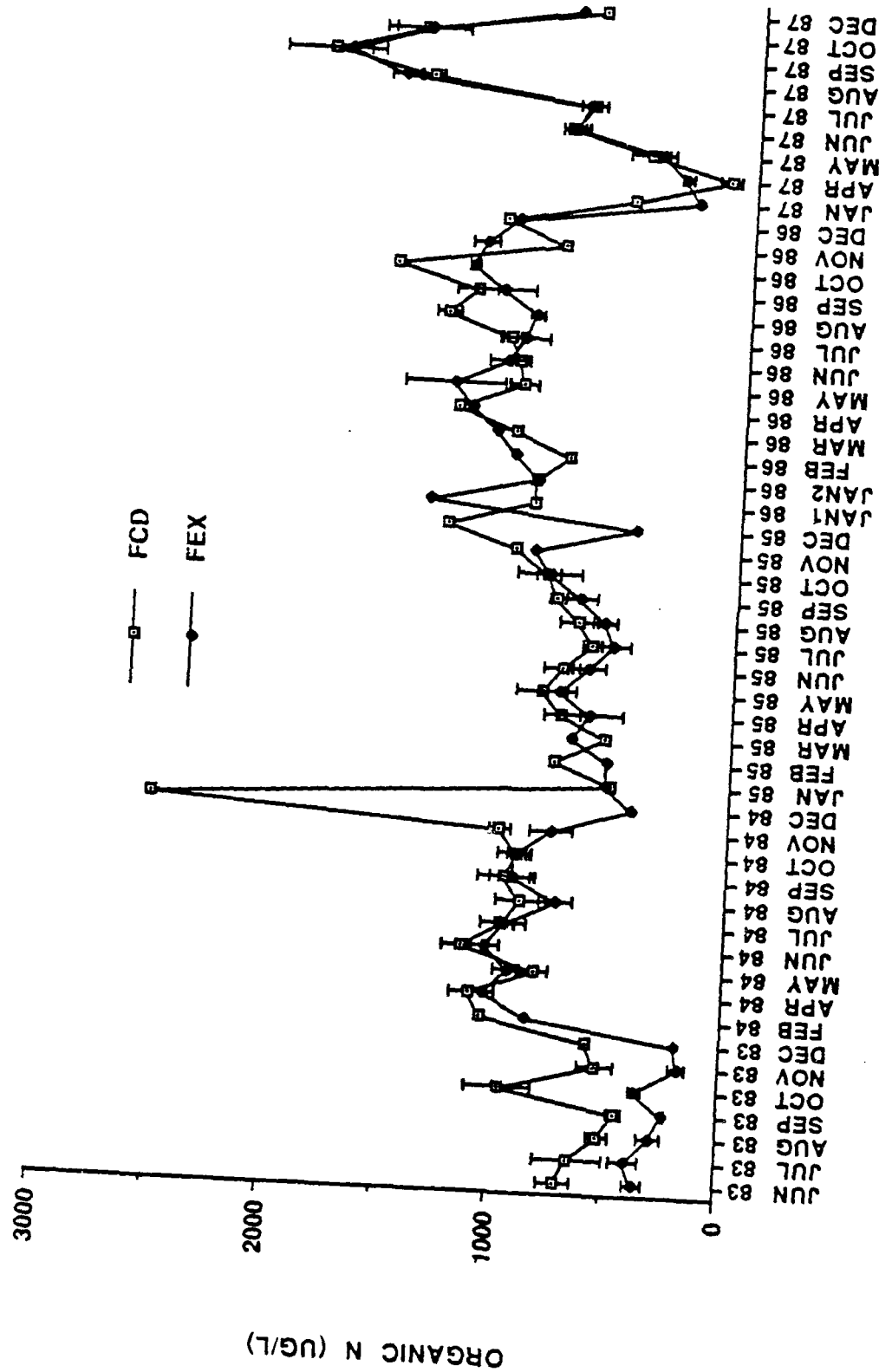


FIGURE 1.17 MEAN ORGANIC NITROGEN CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1988.

Table 1.10 Dissolved Silica (mg Si/L) and Chloride (mg Cl/L) for the Ford River for 1987.  
Values are Means  $\pm$  S.E. in parentheses

Dates	Silica		Chloride	
	Control (FCD)	Experimental (FEX)	Control (FCD)	Experimental (FEX)
1/9/87	8.7	9.1 (1)	4.8 (1)	5.8 (1)
2/6/87	9.5 $\pm$ 0.8	9.4 $\pm$ 0.2 (2)		6.3 $\pm$ 0.5 (2)
3/6/87	9.3 $\pm$ 1.0	9.3 $\pm$ 0.3 (2)		6.8 $\pm$ 0.0 (2)
4/3/87	7.9 $\pm$ 0.4	6.9 $\pm$ 2.2 (2)	6.2 $\pm$ 0.0 (2)	6.5 $\pm$ 0.4 (2)
5/1/87	7.2 $\pm$ 1.5	4.3 $\pm$ 0.3 (3)	4.8 $\pm$ 1.2 (3)	5.8 $\pm$ 0.3 (2)
5/26/87	4.9 $\pm$ 0.3	4.5 $\pm$ 0.3 (8)	3.3 $\pm$ 0.4 (8)	4.0 $\pm$ 0.5 (8)
5/22/87	6.4 $\pm$ 0.5	6.7 $\pm$ 0.3 (9)	4.0 $\pm$ 0.4 (9)	4.0 $\pm$ 0.3 (9)
7/20/87	8.2 $\pm$ 0.2	8.4 $\pm$ 0.1 (9)	3.8 $\pm$ 0.3 (9)	4.0 $\pm$ 0.2 (9)
8/31/87	9.1 $\pm$ 0.3	9.8 $\pm$ 0.2 (9)	4.6 $\pm$ 0.2 (9)	4.9 $\pm$ 0.2 (9)
9/28/87	7.5 $\pm$ 0.6	8.9 $\pm$ 0.3 (9)	5.0 $\pm$ 0.3 (9)	5.0 $\pm$ 0.2 (9)
10/26/87	8.1 $\pm$ 0.5	8.8 $\pm$ 0.2 (9)	4.6 $\pm$ 0.5 (9)	4.8 $\pm$ 0.5 (9)
12/27/87	8.5	8.5 (1)	5.7 $\pm$ 0.1 (2)	5.2 $\pm$ 1.0 (2)

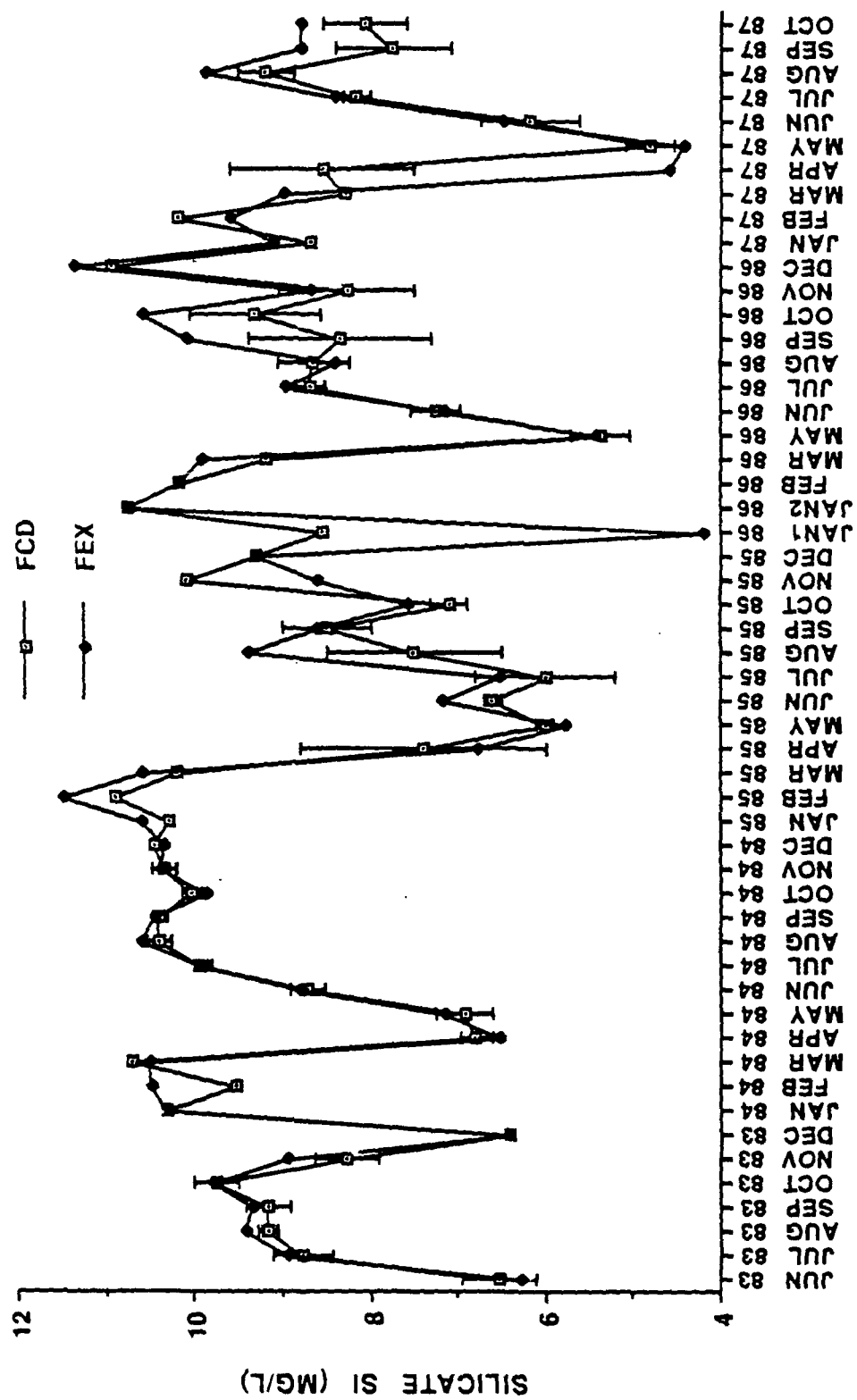


FIGURE 1.18 MEAN SILICATE CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1988.

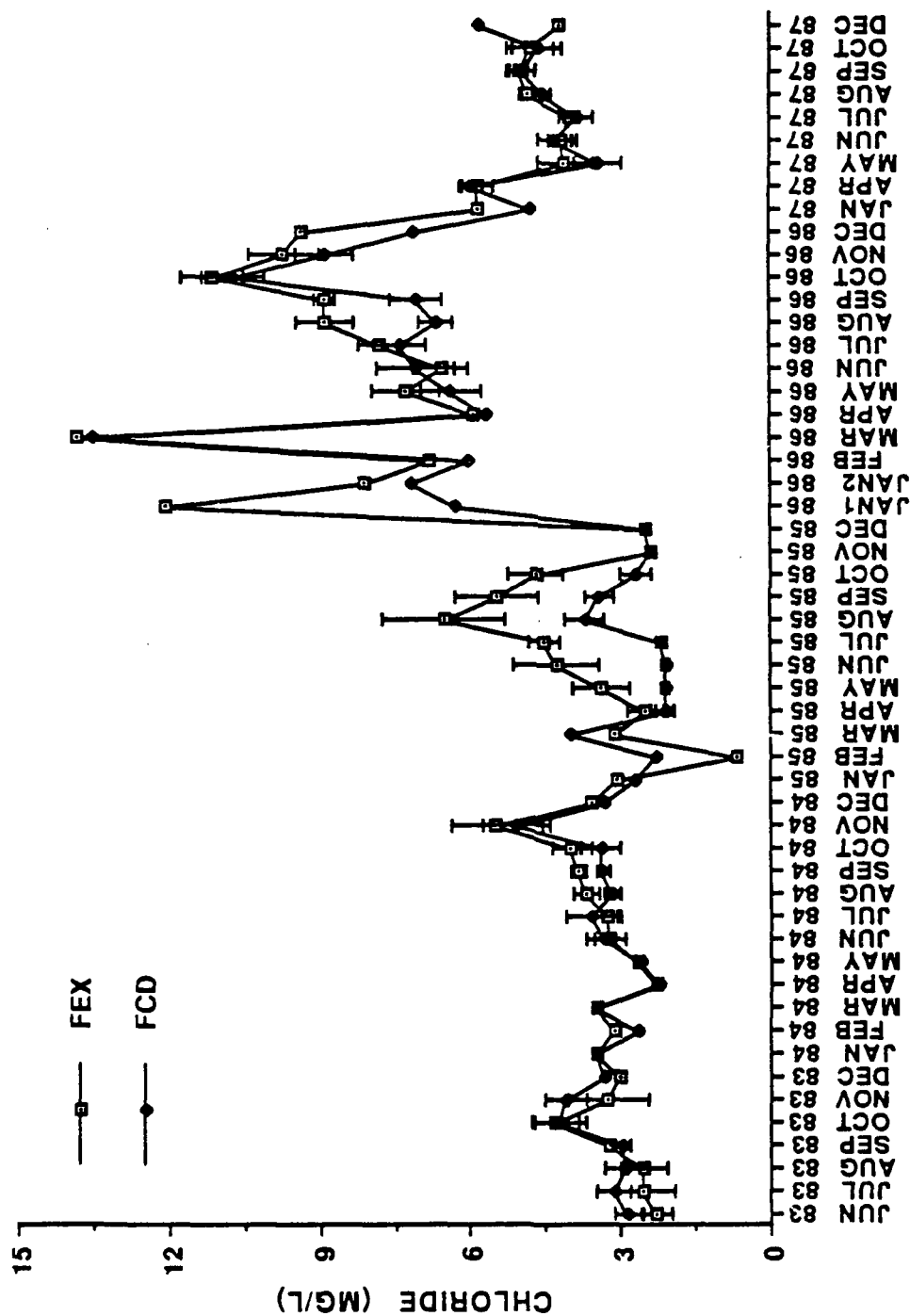


FIGURE 1.19 MEAN CHLORIDE CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD  
FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES,  
1983-1988.

concentrations at FEX were significantly related to concentrations at FCD (Table 1.7). Concentrations were relatively constant throughout the year at about 9 to 10 mg Si/L, although periods of dilution did occur during high flows in April or May each year and during other periods of high discharge (Fig. 1.18, 1.7, 1.8). In fact, silicate-Si was significantly ( $p < 0.05$ ) and negatively correlated with discharge at both FEX and FCD, although  $r$  values were low ( $-0.39$  at FEX and  $-0.34$  at FCD).

Chloride at FEX was significantly different from chloride at FCD prior to 1987, but these differences disappeared in 1987 (Table 1.7, 1.10, Fig. 1.19). Values for the two sites were significantly correlated in 1987 (Table 1.7), as they had been in previous years. Concentrations of Cl appeared to be larger at the upstream site (FEX) in 1985 and 1986 than they were at the downstream site (FCD). This gradient may have reflected the fact that some of the chloride inputs were from road salting near Channing, MI with dilution of these inputs in a downstream direction. Chloride concentrations increased in 1986 but in 1987 dropped back to values typical of the time period from 1983 through 1985. The reasons for this increase in 1986 followed by a decrease in 1987 are unknown. However, these values are not much higher than one would expect from rainwater and are certainly much lower than any concentration known to cause problems for fish or other aquatic organisms (McKee and Wolf 1963).

### C. Physical and Meteorological Parameters

The primary physical parameters monitored include air and water temperature, above and below water photosynthetically active radiation (PAR), and stream discharge. These data are automatically logged at 30 minute intervals from mid-April through the end of October. Almost no data are available from the winter months.

Solar radiation (PAR) was highly variable using the 30 minute interval data. An integrating instrument would have provided more useful data but was not included in our original equipment list. Our 28 day summaries have been calculated as an average of the 30 minute PAR values for the period from 1000 to 1400 hours daily (Fig. 1.20). These data from the experimental site (FEX) are characteristic of data from both sites. We have a good record of PAR value at FEX, but a gap in above water PAR data at FCD does exist. The above water PAR data for FEX has been taken in open unshaded areas thus far. Therefore, one would expect only minor

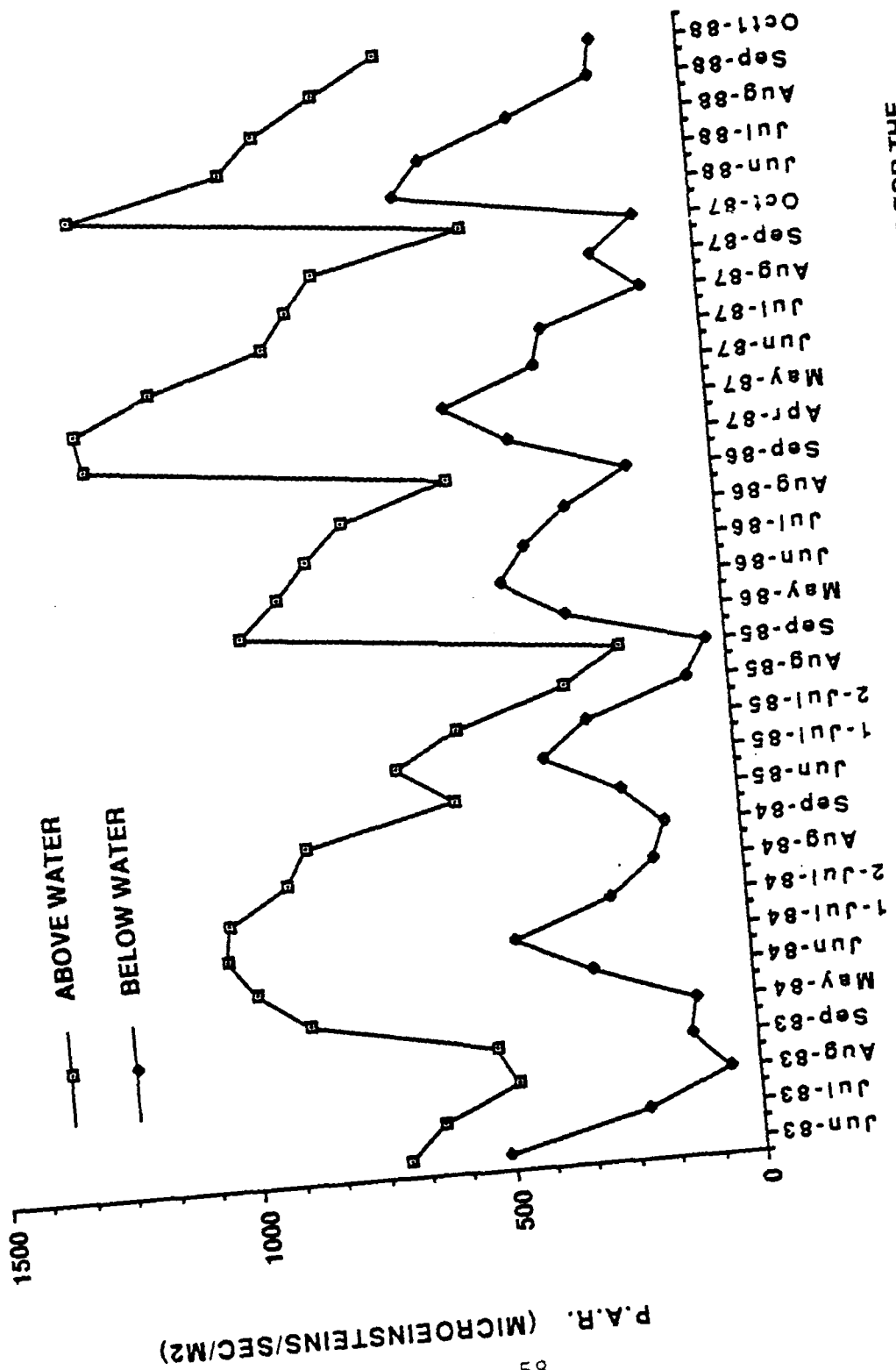


FIGURE 1.20 MEAN SOLAR RADIATION FOR EACH 28 DAY PERIOD FOR THE  
 FORD RIVER AT FEX, 1983-1988.

variations from site to site. This approach results in comparative data for each 28 day period but may have little meaning biologically. A more appropriate measure might be cumulative solar input for each 28 day exposure period. As reported in the last annual report, we intend to calculate this cumulative solar input data for all past periods based on the 30 minute interval data. Obviously, such 30 minute based data calculations will not be very precise but will give us a comparative index of solar input as it varies seasonally. We have not yet finished this task but will include it and/or a degree day approach to our final correlations between data on the biota and physical parameters.

Air and water temperature have been monitored since 1983 and are available as needed. The water temperatures for 1988 are typical (Fig. 1.3, 1.21) of data over the growing season with temperatures rising rapidly from at or near zero under ice to 5 to 10° C before our monitoring stations are installed. Temperature continues to rise to mid-summer from mid-June through mid-August followed by cooling to about 5° C when the stations are removed from the stream. On subsequent monthly sampling trips from November through April, stream temperatures are at or near zero. The average temperature data for the 28 day exposure periods for the benthic algal sampling are summarized in Fig. 1.21. These data illustrate that average summer temperatures have been less than 20° C for every summer except 1983 and 1988 with 1988 attaining the highest average temperatures since the start of the study.

Stream discharge data have already been presented for the 28 day benthic algal exposure periods (Fig. 1.7) and for mean daily values for 1988 (Fig. 1.8). However, the first three years of these data were calculated from actual discharge measurements taken with current meters once or twice per week. Initially, data were logged on Omnidata pods using modified Stevens Type F recorders. These data had to be converted to discharge using two regressions. The first related electrical output from the recorders to the datapods to actual water depth. The second related water depth to discharge using a standard depth-discharge regression. The first of these regressions changed any time the float line was set to a different position on the float wheel. Thus, retrieval and conversion of these data proved to be quite a chore. It has not yet been completed. In 1986, this system was abandoned and the simple but effective strip chart recorder has been used since. Data on mean daily flows are

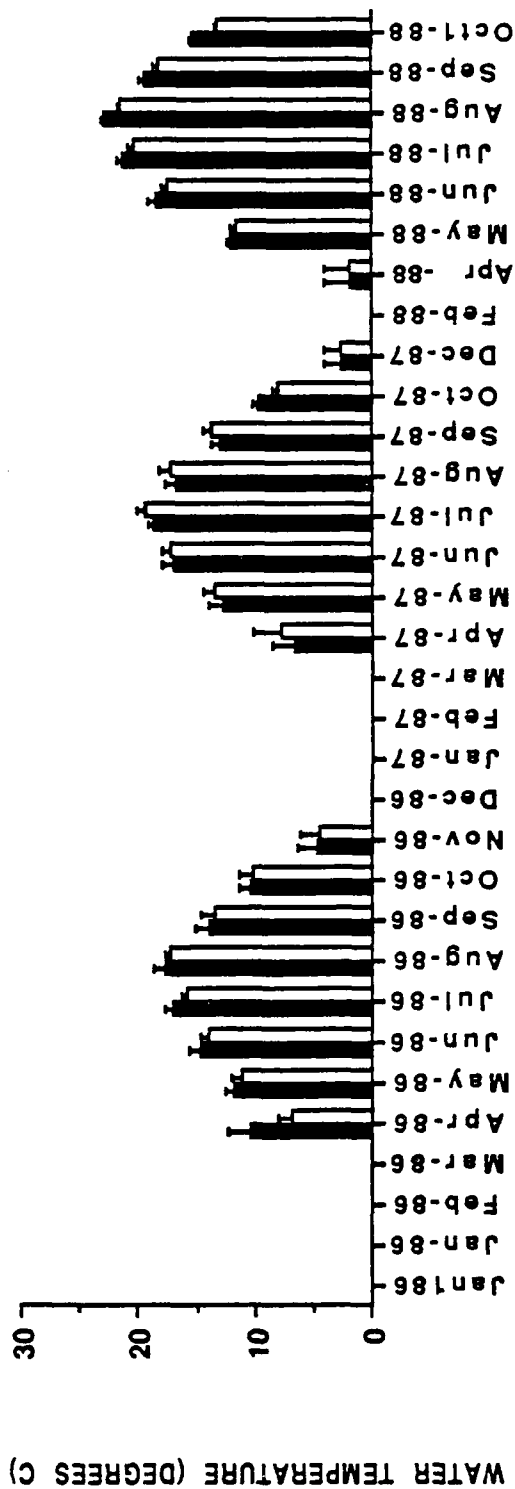
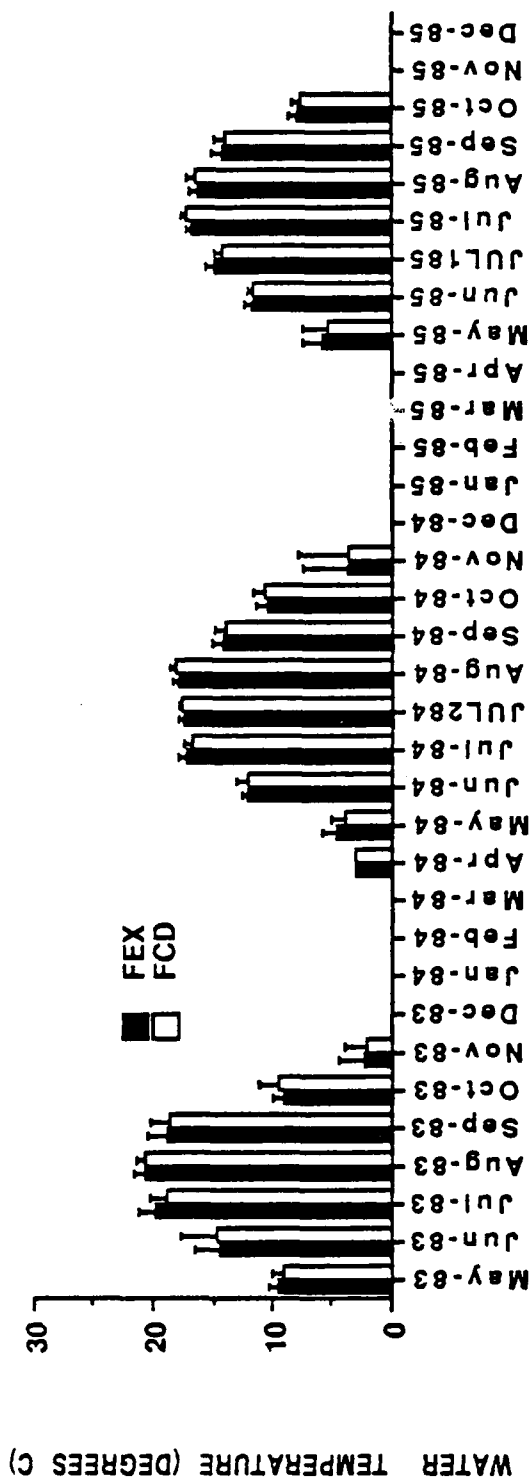


FIGURE 1.21 MEAN WATER TEMPERATURE (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1988.



currently available for all years since 1986. We hope to retrieve the data from the first three years. Eventually, we expect to calculate regressions of the biological parameters with mean discharge, minimum discharge, maximum discharge, peak discharge values, time since last storm event, etc. for each of the 28 day benthic algal exposure periods. We suspect, for example, that maximum production of benthic algae occurs during times of low discharge with amount of production probably correlated with the length of time since the last storm.

Another way to get at the time since the last storm is to correlate the biological data with time since last major precipitation event. We are relying on National Weather Service data for Crystal Falls for these correlations. Entering this data into our data base was a priority for the winter of 1987-88. We completed this task and have included these data in correlations discussed in Element 2. Since Crystal Falls, MI data may not be precise for the Ford River watershed, we have collected supplemental rainfall data for each site for the last four summers. These data for 1988 are presented in Fig. 1.22.

#### D. Summary

Data for all chemical and physical parameters demonstrated that the experimental and control sites were very well matched. For the majority of the parameters, there were no significant differences between sites. When significant differences did occur between the chemical constituents, they usually involved a slight increase in a downstream direction. This trend had been true for hardness, nitrate, and organic nitrogen prior to this year. This year the differences for nitrate and organic nitrogen disappeared. The differences observed for hardness and for nitrate and organic-N in prior years could be related to an expected accumulation of dissolved load in a downstream direction or to local land use differences between sites. Whatever the cause, the differences were small and probably would not lead to significant intersite differences in productivity. We initiated experiments in 1987 to determine the impact of N and P inputs on the algal community. Both had to increase before significant changes in the algal community occurred. Clearly, no such shift in N and P has occurred.

Dissolved oxygen was only slightly below saturation at both sites but was slightly but significantly higher at FEX than it was at FCD for data reported prior to 1988. We postulated that this difference was probably related to

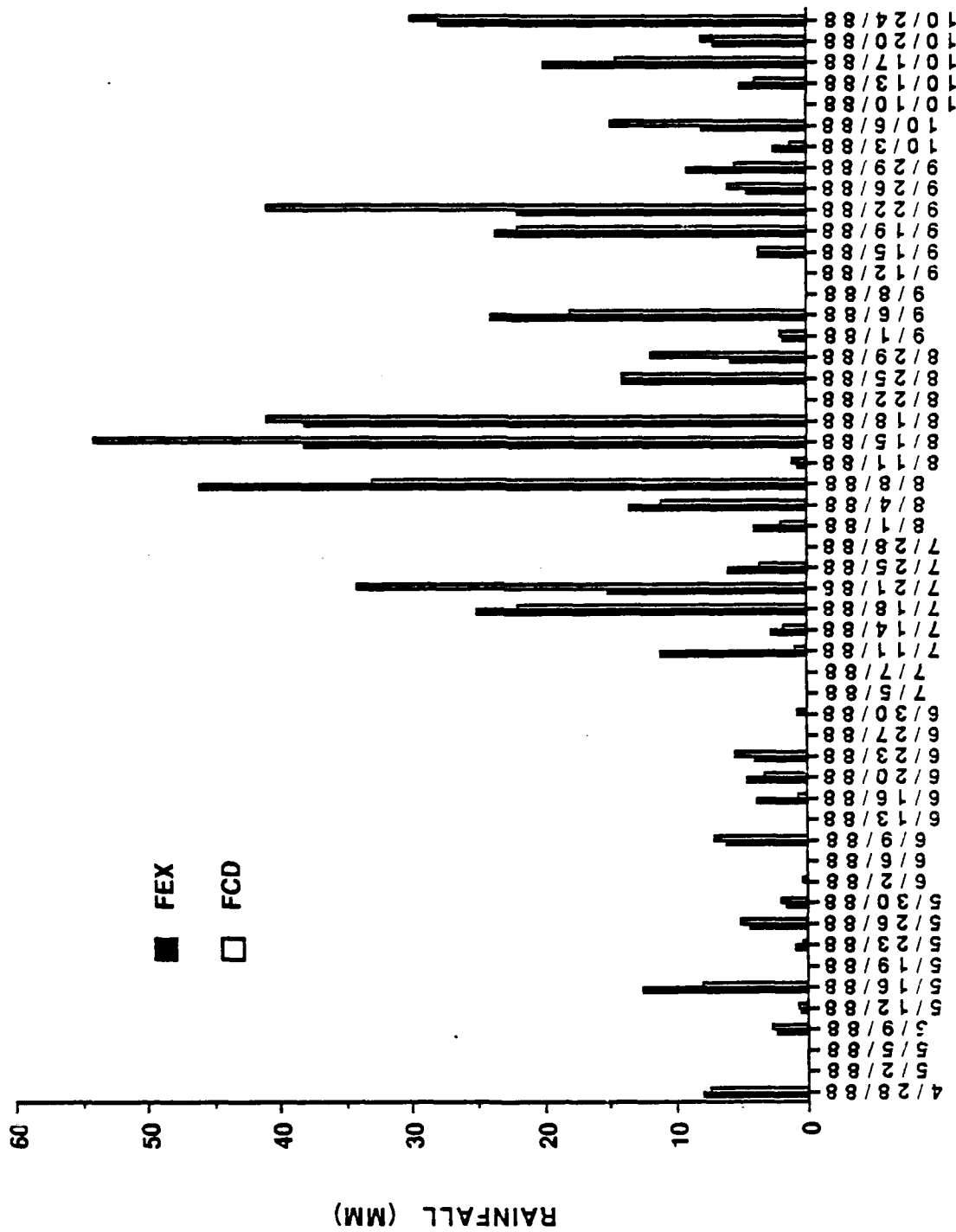


FIGURE 1.22 DAILY RAINFALL AMOUNTS FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES FOR 1988.

differences in sample times between the two sites. In 1988, we alternated sampling times for the two sites and differences between sites disappeared.

Chloride also was slightly but significantly higher at FEX than it was at FCD prior to 1988. This difference might reflect a slight amount of road salt influence from Highway M-95 at Channing, MI that is diluted in a downstream direction. This previously observed difference between the two sites did not occur in 1988. Even at FEX, chloride levels were only slightly higher than typical rainfall values. Thus, chloride should have little effect on the biota at either site.

Chemical and physical parameters for FEX and FCD demonstrated that these two sites were very similar with significant differences between sites showing up for less than one-third of the parameters monitored prior to 1988. The differences that did occur were slight and should have little impact on site productivity. Most of these differences disappeared in 1988 with the exception of water temperature and hardness.

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## IX. A. PERIPHYTON STUDIES

Element 2 - Monitoring of Species Composition, Numbers, Diversity, Organic Matter Accrual Rates and Standing Crop, Cell Volume, and Chlorophyll a/ Phaeophyton a Accrual Rates and Standing Crop for Periphyton.

Changes from workplan- The winter sampling schedule for the biological parameters was changed from monthly (28 days) to bimonthly sample collection beginning October 1987. The biological data reported for 12/27/87 and 2/28/88 are from slides exposed for 63 and 62 days, respectively. This change was suggested and approved during the review of the last annual report (AE-071).

### Objectives

The objectives of the periphytic algal studies are:

- (1) to monitor any changes in chlorophyll a and organic matter accrual rates and standing crops as a result of ELF electromagnetic fields,
- (2) to determine algal cell volumes and chlorophyll a to phaeophytin a ratios, thereby providing indices of physiological stress in periphytic algal cells that might occur as a result of ELF electromagnetic fields.
- (3) to quantify any changes in species diversity, species composition, species evenness, and cell density that occur as a result of ELF electromagnetic fields, and,
- (4) to quantify any changes in primary productivity that might occur as a result of ELF electromagnetic fields.

### Rationale

Structural Community Indices: Community composition of the attached algae has often been used by researchers to indicate subtle or dramatic changes in water quality. The effects of toxins, nutrients, or other pollutants has often been linked to changes in abundances of particular diatom species and often to the presence or absence of sensitive species. The use of a species diversity index coupled with measurements of species evenness and percent dominance allows between site comparisons of attached algal communities to

detect subtle shifts in species composition that may occur as a result of ELF radiation. The diatom community which develops on exposed glass slides often consists of 50-70 species on a single slide out of an estimated species pool for the Ford River of over 350 species. Changes in species abundance, species diversity, and species evenness of this community provide sensitive and statistically measurable parameters against which to measure seasonal variation, site variation, yearly variation and potential ELF effects.

In addition to studying the species composition of the attached algae, we are examining the relatively simple parameter of overall cell density. This directly determined density measure represents the numerical end product of species succession and abundance or dominance shifts by individual species in the attached algae community, and also includes the effects of physical environmental factors. The use of cell density, which is affected by both biological and physical factors, may reveal changes due to ELF effects. This single parameter is also a very important correlate with other estimates of production, such as chlorophyll *a*, or organic matter accrual. This labor intensive direct counting procedure is the yardstick against which other production estimates are often compared and should help separate potential ELF induced effects from other biological or physical influences.

**Functional Community Indices:** Measurement of the amounts of chlorophyll *a*, the primary photosynthetic pigment used by all algae, provides both quantitative and qualitative comparisons between sites. The quantity of chlorophyll *a* present can be directly measured through the intensity of its fluorescence and can be correlated with cell density and individual average cell volume to indicate the relative or qualitative physiological state of the algal community. Subtle effects of ELF electromagnetic fields on the photosynthetic pigment may result in cellular "leaking" or a general physiological weakening of individual cells. This weakening may decrease both the total quantity of chlorophyll *a* present, as well as reduce the amount of oxygen generated through photosynthesis. The ratios of chlorophyll *a* to the main chlorophyll *a* degradation product, phaeophytin *a*, along with site comparisons of the relative amounts of oxygen produced by attached algae can also indicate the degree of physiological stress in the algal community.

This multiple approach of methodologies couples direct determinations of quantities of pigments present with indirect physiological measurements of pigment condition, with further direct measurements of oxygen levels produced by that pigment. Thus, these parameters allow

statistical comparisons of production between sites throughout the year. Utilizing several different approaches allows us to continue analyses at times when we must rely on single approaches due to weather or labor constraints. For example, measuring chlorophyll *a* and organic matter accrual directly during winter provide estimates of production when the more detailed production studies of photosynthetic rates are not feasible.

In 1986 and 1987, we investigated a new statistical procedure defined by Stewart-Oaten *et al* (1986) to determine the suitability of this technique for analyses of the kinds of structural community indices that we were examining on the Ford River. The analysis, referred to as the BACI test, was demonstrated in the 1986 annual report to illustrate the technique and to see if it would be useful for significance testing on single species population abundances. Last year we continued our investigations into the use of the BACI analysis for functional indices, particularly chlorophyll *a* and AFDW-biomass. In order to test the potential of the BACI technique to detect more subtle changes over time, we have used the method this year to examine seasonal variations of each of the biological parameters from 1983 to 1988.

Thus, our rationale has been to provide multiple data sets taken independently to be used in determinations of structural and functional indices, incorporating several methodologies in order to detect and separate any "real" differences as a result of ELF electromagnetic radiation from either background variability or errors associated with a reliance on a single method of data collection or analysis.

#### Materials and Methods

Plexiglass slide racks were designed to hold 8 or 10 standard 7.6 x 2.5 cm glass slides in a vertical placement oriented facing the current in the river. These slide racks were fastened to bricks and placed in riffle habitats at the control (FCD) and experimental sites (FEX). Slides were removed after 14 days for chlorophyll *a*, phaeophytin *a*, and AFDW-organic matter accrual rates and after 28 days (62 or 63 days during winter 1987) for species composition and cell count determinations, chlorophyll *a*, phaeophytin *a*, and AFDW-organic matter standing crop determinations. Ten slides per site were used for each determination, except that this number was increased to 25 during the winter of 1987-88.

For species composition, cell counts, and cell volume determinations, 5 slides were removed on each sampling period

from each habitat. Three slides were air dried and the other two were placed in a mixture of 6 parts water, 3 parts 95% ethanol and 1 part formalin (6:3:1 solution). These numbers were doubled during winter sampling in 1987-88. The air dried slides were later scraped in the lab with razor blades to remove the diatoms for further specimen cleaning and slide preparation. The slides preserved in the 6:3:1 solution will be used to determine species composition of non-diatom algae should this prove necessary. Preliminary comparisons have indicated that non-diatom algae comprise a minor component of the algal community in the Ford River. Thus, we have chosen to emphasize studies of diatoms.

Slides were prepared for specimen identification by cleaning the diatoms removed from the exposed glass slides in concentrated hydrogen peroxide (30%) followed by further oxidation of the cellular contents with the addition of small amounts of potassium dichromate (Van der Weff 1955). The cleaned diatoms were then rinsed with distilled water and settled in graduated cylinders. The final volume of concentrate containing the cleaned diatom frustules was then measured and 1 ml subsamples pipetted onto 22 mm<sup>2</sup> coverslips, until an adequate counting density was achieved. The coverslips were air dried and permanently mounted on glass slides using Hyrax medium.

Counting to determine diatom density calculations, and species determinations was done at 1250X magnification on a Zeiss microscope equipped with phase contrast illumination and an oil immersion 100X Neofluar phase objective with numerical aperture of 1.30. Transects were taken moving across the coverslip until between 300-400 frustules were counted. Estimates of diatom densities were then calculated from these quantitative samples via the equation:

$$\text{Cells m}^{-2} = \frac{(\text{Valves Counted}) (\text{Area Coverslip}) (\text{Volume Concentrate})}{2 (\text{Area Transect}) (\text{Volume Subsample}) (\text{Area Sampled})}$$

Diatom species composition was recorded for each slide counted for determination of species richness, diversity (H') using the Shannon-Wiener formula (Southwood 1978; chosen for its more universal use and acceptance than other more obscure diversity indices), species evenness (J') (Pielou 1969, p.233), and dominance. Cell volume measurements were taken by measuring lengths, widths and depths and recording shapes of dominant diatoms for calculation of cell volume based on geometric formulae or combinations of various geometric volumes.



Analyses for both chlorophyll a and phaeophytin a followed the fluorometric determination described in Method 1003C in Standard Methods (APHA 1980). All samples were analyzed within a month of collection. Initial analyses suggested no differences in these parameters whether or not the samples were ground first with a tissue homogenizer to facilitate cellular rupture. Therefore, this step was eliminated. Slides were collected, frozen for at least 24 hours to promote cell rupture, and then pigments extracted in 90% buffered acetone. Chlorophyll a and phaeophytin a were then determined following procedures outlined in Standard Methods.

Organic matter biomass determinations were conducted following procedures 1003D for productivity estimates in Standard Methods (APHA 1980). While using the gain in ash-free dry weight per unit area as a measure of net bacterial and algal production (APHA 1980), we recognize that determining rates of primary production from a temporal series of biomass measurements results in minimal estimates of net production. The losses that may occur from excretion of organic compounds, respiration, mortality, decomposition, emigration, or grazing are certainly not included in determining this production estimate (Wetzel 1975). Likewise, accumulations of organic matter from physical processes such as flocculation or settling of dissolved and particulate organic matter are also possible (Lock et al. 1984). The accrual of organic matter biomass is a combination of processes involving dynamics of both colonization and production as well as physical processes. Results from our study of the colonization component on biomass accrual should increase the accuracy of these production estimates. Rather than list results as production, however, we will refer to them as organic matter accrual rates or AFDW-biomass accrual rates.

Statistical comparisons between sites emphasize the paired-t test, as recommended by one of our reviewers in past annual reports. Single year data for October, 1987 through September, 1988 and results for yearly and five year paired t-tests on all parameters measured will be presented in this report. As in past reports, we have also calculated a correlation matrix using all biological, ambient, and nutrient data to provide a complete picture of potential relationships. Additionally, emphasis has been placed on the analysis of biological parameters using the BACI technique. Previous methods for analysis of "before" and "after" ELF effects as presented in earlier annual reports included the 3-way analysis of variance. The variables included a year,

site and month effect for the selected parameter. While this analysis may prove to be the most statistically robust of several analyses available, they all may suffer from lack of true replication (Hulbert 1984). Because of such considerations and to expand our methods, we have analyzed our biological data according to the BACI method presented by Stewart-Oaten et al (1986). The design requires replicated sampling over time; Before and After the antenna is operating at both Control and Impact sites.

The BACI design determines whether the difference between simultaneously collected samples of a given parameter at Impact (FEX) and Control (FCD) sites has changed significantly with antenna operation. The mean of the "before" differences between sites is compared to the mean of the "after" differences between sites by using an unpaired t-test. If the magnitude of the difference between the control and impact sites changes significantly ( $p < 0.05$ ) after impact, there is a significant antenna impact. The procedure assumes that the following criteria are met: (1) the measures of the parameters at any time are independent of the measures of those parameters at any other time, and (2) the differences between the control and impact sites of the "before" period are additive, or relatively constant. The first criterion was met by the sampling regime used in our study. The parameters we examined were measured independently for 28 or 62 day periods. The second condition was satisfied by transforming the data, if necessary (Steel and Torrie 1986). If regression of the differences versus the average at both sites for the raw or transformed data produced a slope that was not significantly different from zero (Tukey's Test for Additivity), the differences were additive. The differences for each period were then compared with an unpaired two-tailed t-test.

Using the BACI analysis, we can examine seasonal variations of chlorophyll a, AFDW-biomass, cell volume, biovolume, cell density, species diversity, evenness, and diatom abundance. Seasons for this analysis consisted of a Summer (May to October) and a Winter (November to April) period, with all seasons prior to Summer, 1986 representing the "before" period. The "after" period commenced July 22, 1986 at FEX with an average 4 amp ELF exposure for variable time periods during the day over 31 consecutive days. During 1987, the site at FEX received 15 amps for variable time periods during daylight hours from May 22 through August 31, 1987. The experimental site was exposed to 75 amps for variable time periods throughout most of 1988. Using the

BACI design we ran lumped comparisons on all the biological data except diatom abundance; i.e. all sampling dates from June, 1983 to April, 1986 as the "before" period and all dates from May, 1986 to September, 1988 as the "after" period. For each biological parameter, seasonal lumped comparisons were run; i.e. Summers (or Winters) 1983, 1984, 1985 as the "before" period and Summers (Winters) 1986, 1987 and 1988 as the "after" period. Additionally, individual seasons of the "before" period for each parameter were compared to other "before" seasons to determine whether any differences occurred prior to impact. Each of the "before" seasons were then individually compared to each of the "after" seasons to see whether significant differences occurred as a result of ELF exposure. We were particularly interested in the comparison of each "before" season with the 1988 data, since 1988 was the year of highest amps (75) used to date as well as the most days of exposure.

While we increase the degree of statistical analyses performed, as well as the complexity of the analyses with each report as more data becomes available, a large inherent variability still remains between our biological field samples collected at one point in time. For example, chlorophyll *a* determinations had coefficients of variation (C.V.'s) that averaged 32% in 84-85, 42% in 85-86, 37% in 86-87, and 34% in 87-88. AFDW-biomass had C.V.'s that averaged 40% in 84-85, 64% in 85-86, 45% in 86-87, and 48% in 87-88. Diatom cell density averaged 38% in 84-85, 39% in 85-86, 33% in 86-87, and 45% in 87-88. All three important biological parameters showed average C.V.'s possibly too high to detect subtle differences due to ELF effects if comparisons are made at one point in time or for a single random sample period only. Derived measurements of species diversity or species evenness calculated from the field samples showed much lower C.V.'s ranging from 1% to 27% and averaging 10% in 85-86, 10% in 86-87, and 6% in 87-88 for species diversity, and species evenness averaging 7% in 85-86, 6% in 86-87, and 4% in 87-88. The individual C.V.'s of many of our monthly samples often fell below the 20% rejection level commonly used in benthic studies (Cummins 1975), in spite of the wide range in C.V. values observed over the course of a year. At such times, when the C.V.'s are low, statistical comparisons made between sites therefore provided a sample size sufficient to be 95% certain of detecting a 40% difference in means between the two sites at the .05 significance level (Sokal and Rohlf 1969). Coefficients of variation tend to be lower during low flow periods in summer and more variable during the higher waters

seen in spring and fall periods. Thus, statistical comparisons in future reports will emphasize these time periods to be able to detect small differences between single time period comparisons. Our main efforts have been to devise tests rigorous enough to detect differences using larger samples over time. We expect overall trends to be examined through the before mentioned BACI technique, and through regression analyses comparing pre-ELF exposure data with post-ELF exposure data and time series analysis. In future reports, we also plan to subject the data to principal components analyses as a means of determining if any parameter loads heavily on the component related to ELF exposure. We used this principal components procedure as a means of examining grazer effects in Element 3 and the reader is referred to that section for an example of the procedure.

## Results and Discussion

### A. Colonization Patterns

In previous annual reports (AE-020, AE-031 and AE-045 for 1982-83, 1983-84, and 1984-85), we summarized data on colonization patterns for periphyton for the Ford River. These data demonstrated that for determining rates of productivity and organic matter accumulation, a 14 day period was best during the active growing season (mid-April to mid-September). This 14 day period coincided with rapid increases in chlorophyll *a*, phaeophytin *a*, and accrual of organic matter. Selecting this early period minimizes losses due to sloughing that increase as the periphyton community "matures" or approaches its maximum sustainable density on the slides (Burton and King 1983). This period of maximum daily increase in organic matter and chlorophyll *a* is often used as a measure of net production (APHA 1980; Burton and King 1983). Since the daily increases are less rapid during the cold weather, we used the 28 day period for estimates of daily productivity or accrual rate during the winter months and the 14 day period from April through October.

After 14-21 days during exposure periods without major flood events, the periphyton community composition was shown to change slowly through time (Oemke and Burton 1986), and qualitatively approximated the mature community on natural substrates in the stream. Thus, standing crop estimates of chlorophyll *a*, phaeophytin *a*, organic matter, and all community composition parameters (cell density, species diversity, species evenness, and species dominance) are based

on a 28 day exposure period throughout the year. All data from 1983-1988, excluding winter of 1987, were based on this 28 day or this 14 day exposure period and sampling regime. As reported in the 1982-83 annual report (AE-20) and in Oemke and Burton (1986), differences between a slow flowing pool habitat, and the more rapidly flowing riffle habitat were either slight or insignificant as exposure length increased. Thus, all samples are presently collected from riffle areas only.

Data on these colonization dynamics were published in Hydrobiologia (Oemke and Burton 1986), and presented as an appendix in the annual report for 1986-87 (AE-071).

#### B. Patterns for Chlorophyll a

Chlorophyll a standing crop data for October 1987 through September 1988 followed annual patterns of summer peaks and winter lows (Fig. 2.1, Table 2.1). Annual patterns have indicated that chlorophyll a peaks during the summer months of July or August. The 1988 peak occurred in July for both sites and reached levels of 13-20 mg m<sup>-2</sup>. These chlorophyll a levels, a result of warmer temperatures and lower discharge associated with the 1988 drought, represent the highest standing crop measured since 1983. In fact, most measures of algal standing crop (density, chlorophyll a, AFDW-organic matter accrual) as well as species composition appear to have increased as a consequence of the very dry weather in May and early summer for the past three years (1986, 1987, 1988). The drought of 1988 continued well into August. Thus, we have graphed data prior to May 1986 using a smaller range of values on the Y axis than have been used since that time. Another consistent pattern for chlorophyll a has been that standing crop has been less than 1.0 mg m<sup>-2</sup> under the ice in winter (Fig. 2.1). As reported last year, winter 1986-87 was characterized as being moderate in severity, with substantially warmer temperatures, resulting in less ice cover for the Ford River. The levels of pigment observed for 1986-87 winter were much greater than those observed in any winter for the previous years (Fig. 2.1). Winter 87-88 chlorophyll a levels were not as dramatic as those reported last year, but were slightly greater than 1.0 mg m<sup>-2</sup> (Fig. 2.1, Table 2.1). Results from the winter correlation matrix showed that chlorophyll a correlated negatively with cumulative snowfall (r=-0.36 at FCD and -0.41 at FEX) but this was only significant (p<0.05) at FEX (0.05 level of significance = -0.39).

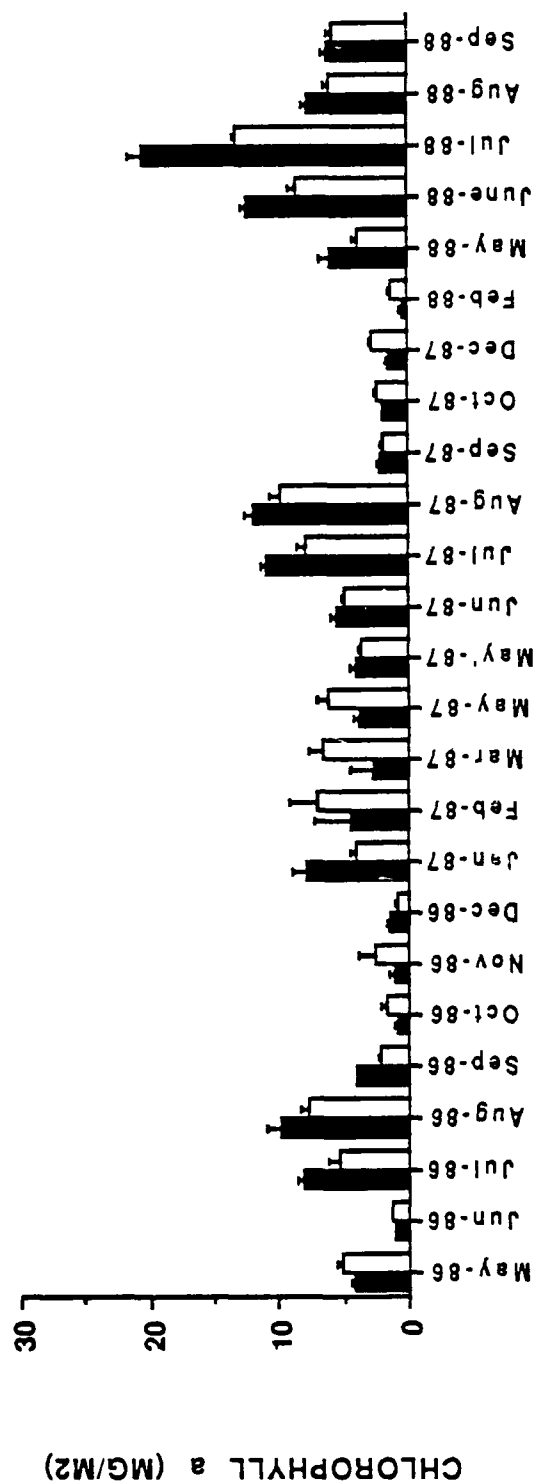
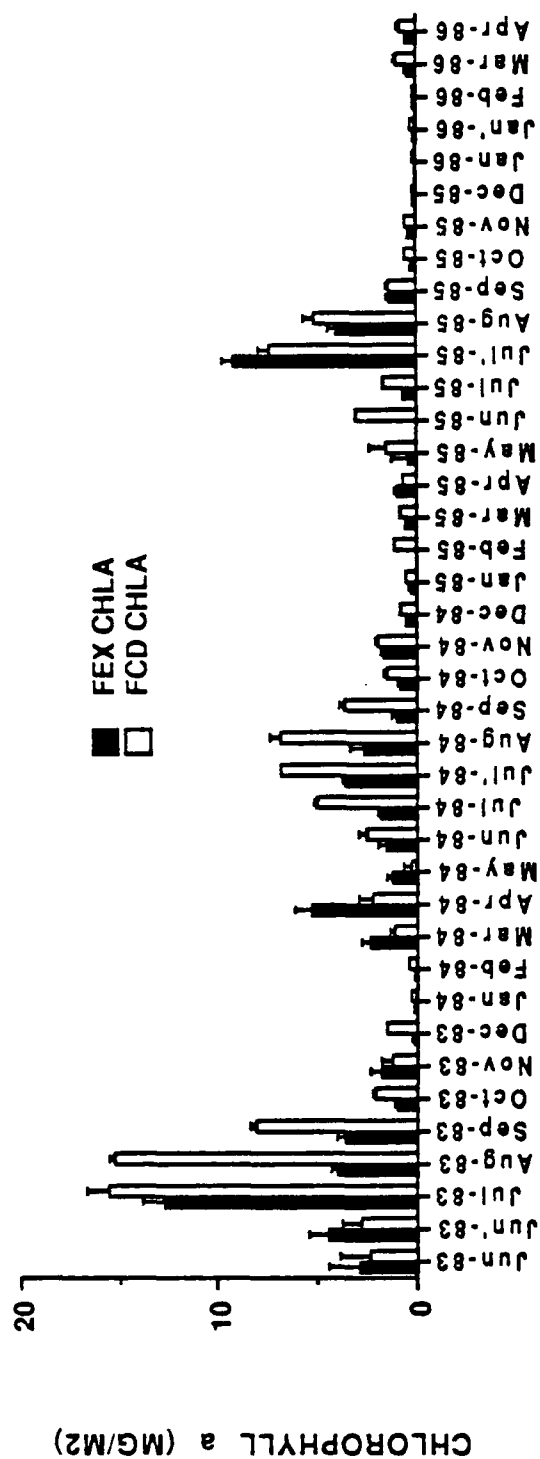


FIGURE 2.1 CHLOROPHYLL a STANDING CROP FOR THE FORD RIVER, 1983-88.

Table 2.1 Chlorophyll a (mg/m<sup>2</sup>) from slides exposed for 28 days in the Ford River (mean  $\pm$  S.E., N in parentheses).

<u>Date Out</u>	<u>Control Site (FCD)</u>	<u>Experimental Site (FEX)</u>
10/26/87	2.39 $\pm$ 0.21 (10)	1.83 $\pm$ 0.18 (10)
12/27/87*	2.79 $\pm$ 0.21 (25)	1.60 $\pm$ 0.21 (25)
2/28/88*	1.32 $\pm$ 0.22 (25)	0.51 $\pm$ 0.08 (25)
5/16/88**	3.87 $\pm$ 0.36 (10)	6.07 $\pm$ 0.83 (10)
6/13/88	8.50 $\pm$ 0.75 (10)	12.33 $\pm$ 0.58 (10)
7/11/88	13.22 $\pm$ 0.27 (9)	20.47 $\pm$ 1.19 (9)
8/8/88	6.04 $\pm$ 0.37 (9)	7.70 $\pm$ 0.47 (9)
9/6/88	5.88 $\pm$ 0.32 (10)	6.19 $\pm$ 0.38 (10)

\* Due to the change in the winter sampling schedule, the data for 12/27 is from slides exposed for 63 days and the 2/28 data is from 62 day exposed slides

\*\* The slides that were to be picked up in April were lost in the river, therefore, the next data set is the 28 day slides from May.

The period of highest annual variability has generally been the periods from late March through June. This period sometimes contains secondary peaks in standing crop production, e.g. April 1984, May 1986 (Fig. 2.1). This secondary peak seems to be associated with dry spring seasons with low flows and relatively warm temperatures following snow melt runoff events. Certainly, May, 1986 was one of the driest and warmest Mays on record. The steadily increasing values for 1988 were also very likely the result of a warm dry spring followed by a very dry June and July (Table 2.1). The five year correlation matrix indicated that chlorophyll *a* was significantly ( $p < 0.01$ ) and positively correlated with water temperature ( $r=0.60$  and  $0.69$  at FEX and FCD respectively) and significantly ( $p < 0.01$ ) and negatively correlated with discharge ( $r=-0.34$  and  $-0.51$  at FEX and FCD respectively). The correlations with water temperature were even stronger when the data from April through October only were considered ( $r=0.64$  and  $0.75$  for FEX and FCD respectively). Thus, temperature and discharge appeared to be two of the primary factors affecting chlorophyll *a*, and the long period of low discharge and high temperatures in 1988 (see Element 1) led to the greater than normal values for this season (Fig 2.1).

There also were significant ( $p < 0.05$ ), positive correlations of chlorophyll *a* with pH ( $r=0.56$  at FEX and  $0.52$  at FCD), conductivity ( $r=0.35$  and  $0.49$  at FEX and FCD), and alkalinity ( $r=0.36$  and  $0.43$ ). The only nutrients significantly ( $p < 0.05$ ) correlated with chlorophyll *a* were nitrate-N and inorganic-N ( $r=-0.34$  to  $-0.39$ ), and both of these parameters tend to be lowest in the summer when uptake by terrestrial vegetation and algae is highest. Thus, the negative correlations seem realistic.

Standing crop levels were higher at the experimental site during May, June, July and August of both 1987 and 1988 (Table 2.1, Fig. 2.1). Even so, these differences were not significant as the annual comparison for 87-88 between sites showed no significant differences using a paired t-test for chlorophyll *a* levels. Chlorophyll *a* levels between sites were highly correlated in 1988 ( $r=.99$ , Table 2.2) just as they were for the entire study period ( $r=0.80$ , Table 2.3).

Last year we reported that results from the 3 way ANOVA on the five year data set indicated a small, but significant, site effect for chlorophyll *a*, and that year and month showed very highly significant effects. Results of BACI comparisons



Table 2.2 Paired t-test and correlations between the Experimental (FEX) and Control (FCD) sites for Biological parameters for 1987-1988.

Parameter	df	Paired t-value	Significance	Correlation Coefficient	Significance
Chlorophyll <u>a</u>	7	-1.560	NS	0.99	P < .01
AFDW	7	0.079	NS	0.55	NS
Chlorophyll <u>a</u> : Phaeophytin <u>a</u>	7	-0.758	NS	0.35	NS
Chlorophyll <u>a</u> daily accrual	7	-1.594	NS	0.89	P < .01
AFDW daily accrual	7	-0.624	NS	0.65	NS
Species Diversity (H')	7	1.384	NS	0.68	NS
Species Evenness (J')	7	2.298	NS	0.79	P < .05
Cell density	7	-1.416	NS	0.86	P < .01
Cell Volume	7	0.017	NS	0.36	NS
Biovolume	7	-1.286	NS	0.72	P < .05

Table 2.3 Paired t-test and correlations between the Experimental (FEX) and Control (FCD) sites for Biological parameters from June 1983 to September 1988.

Parameter	df	Paired t-value	Significance	Correlation Coefficient	Significance
Chlorophyll a	63	-0.809	NS	0.795	P < .01
AFDW-Biomass	63	-0.64	NS	0.701	P < .01
Diatom Density	63	0.082	NS	0.757	P < .01
Average Cell Volume	63	-0.885	NS	0.958	P < .01
Total Biovolume	63	1.323	NS	0.712	P < .01
Diversity	63	-1.599	NS	0.851	P < .01
Evenness	63	-0.91	NS	0.796	P < .01

of 5.5 year  $\log(x+1)$  transformed chlorophyll *a* data (Table 2.4) indicated that a significant difference ( $p < 0.05$ ) occurred when "before" (6/83-4/86) and "after" (5/86-9/88) means were compared with an unpaired t-test ( $df = 62$ ,  $t\text{-value} = -2.328$ ). When broken down on a seasonal basis, the significance was the result of a significant difference between S 83-85/86-88 summer regressions (Table 2.4). Since all the yearly "after" data were additive in 86, 87 and 88, as demonstrated in the Before and After columns for Tukey's test for Additivity in Table 2.4, the significant difference probably reflected the unusually high chlorophyll *a* levels observed during the low flow, hot summers. Summer by summer comparisons showed that these differences primarily arose from differences between the summer of 83, 84, and 85 and the summers of 87 and 88; i.e. S 83/88, S 84/87, S 84/88, SS85/87, and S 85/88 comparisons as presented in Table 2.4. There were no differences between sites based on the paired t-tests (Tables 2.2, 2.3), so it seems likely that these differences in before and after data are a result of different weather conditions and not due to ELF effects. The BACI analysis appears to be sensitive to year to year variations in weather, as well as potential ELF effects. We will continue our BACI summer lumped comparisons to test this hypothesis. Winter data for 86-88 were additive, but since the 83-85 "before" data were not, winter lumped comparisons could not be run (Stewart-Oaten *et al* 1985).

Chlorophyll *a* standing crop was significantly ( $p < 0.01$ ), positively correlated with cell density ( $r = 0.45$  for both FEX and FCD), and AFDW-organic matter standing crop ( $r = 0.47, 0.41$  for FEX and FCD respectively) and significantly ( $p < 0.05$ ), negatively correlated with diversity ( $r = -0.38$  and  $-0.31$  for FEX and FCD).

Daily chlorophyll *a* accrual rates followed the same pattern as did standing crop with June-July peaks and winter lows (Fig. 2.2, Table 2.5). For 1987-88, the June peaks ranged from  $0.4$  to  $0.6 \text{ mg m}^{-2} \text{ d}^{-1}$  and  $0.2$  to  $0.7 \text{ mg m}^{-2} \text{ d}^{-1}$  in July (Fig. 2.2, Table 2.5). These peak daily rates in June and July were above those observed in any previous year. The daily accrual rates were very similar between FEX and FCD, and there were no significant differences between the sites in 1987-88 (Table 2.2). Differences were found to be significant between sites in the report for 1983-84, analyzing only a single year's data by paired t-tests. Since then, greater care has been taken to place slides in similar habitats with respect to current velocity (Fig. 2.3), shading, and depth. Subsequent reports have shown no

Table 2.4 Results of BACI Comparisons of Chlorophyll *a* between Control (FCD) and Experimental (FEX) Sites, 1983-88.

Comparison; (Bel/Alt, Bel/Bel, or Alt/Alt)	Tukey's Test for Additivity*				1 - test†		Sig. p < 0.05
	BEFORE Prob.	Sig. p < 0.05	DF	AFTER Prob.	Unpaired t-value	Probability (two-tailed)	
6/83-4/86 5/86-9/88	0.244	NS	24	0.017	-2.328	0.023	S
S 83-85/86-88	0.455	NS	16	0.006	-4.067	0.0003	S
S 83/84	0.526	NS	6	0.056	0.361	0.725	NS
S 83/85	0.526	NS	6	0.266	-0.074	0.943	NS
S 83/86	0.526	NS	5	0.252	-1.495	0.166	NS
S 83/87	0.526	NS	5	0.085	-1.753	0.110	NS
S 83/88	0.526	NS	4	0.395	-2.285	0.048	S
S 84/85	0.056	NS	6	0.266	-0.662	0.521	NS
S 84/86	0.056	NS	5	0.252	-2.141	0.056	NS
S 84/87	0.056	NS	5	0.085	-2.516	0.029	S
S 84/88	0.056	NS	4	0.395	-3.090	0.011	S
S 85/86	0.266	NS	5	0.252	-1.962	0.076	NS
S 85/87	0.266	NS	5	0.085	-2.599	0.025	S
S 85/88	0.266	NS	4	0.395	-3.546	0.005	S
S 86/87	0.252	NS	5	0.085	-0.120	0.907	NS
S 86/88	0.252	NS	4	0.395	-1.209	0.258	NS
S 87/88	0.085	NS	4	0.395	-1.929	0.086	NS
W 83 85/86-87	0.020	S	7	0.926	1.134	0.268	NS
W 83/84	0.086	NS	5	0.679	0.814	0.434	NS
W 83/85	0.086	NS	6	0.012	0.792	0.445	NS
W 83/86	0.086	NS	5	0.821	0.783	0.452	NS
W 83/87	0.086	NS	1	-	1.142	0.297	NS
W 84/85	0.679	NS	6	0.012	-0.285	0.781	NS
W 84/86	0.679	NS	5	0.821	0.214	0.835	NS
W 84/87	0.679	NS	1	-	1.852	0.114	NS
W 85/86	0.012	S	5	0.821	0.367	0.720	NS
W 85/87	0.012	S	1	-	3.188	0.015	S
W 86/87	0.821	NS	1	-	0.572	0.588	NS

\*Data was log (x+1) transformed

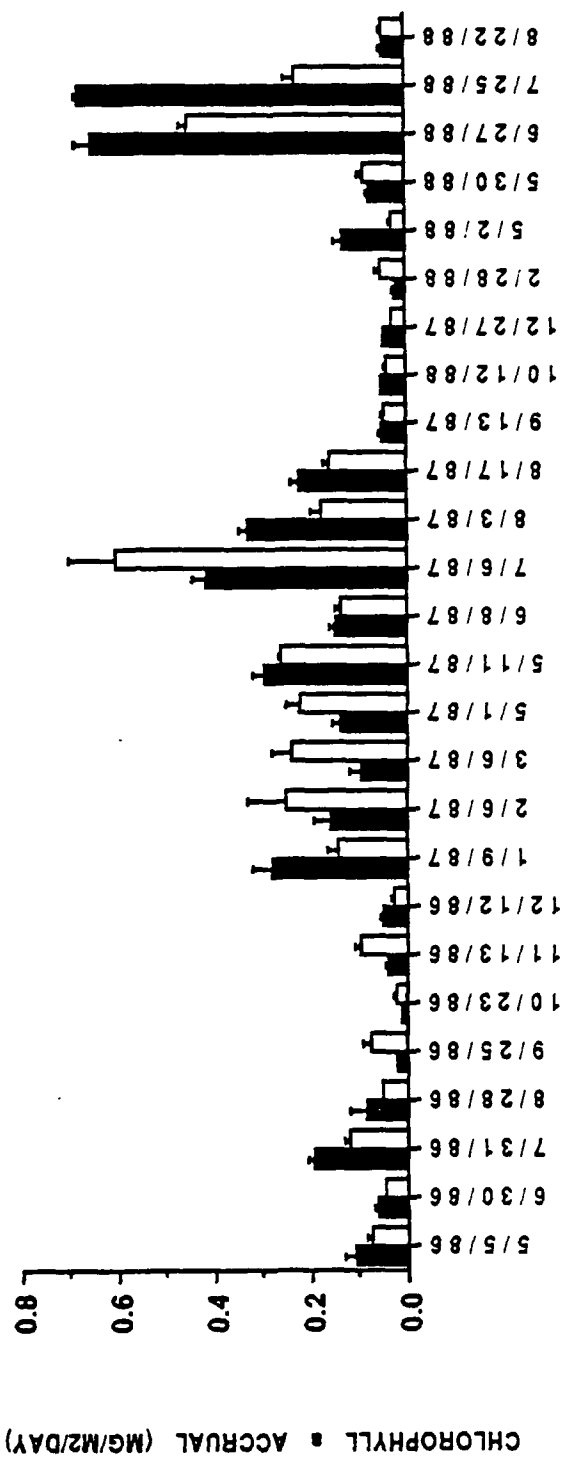
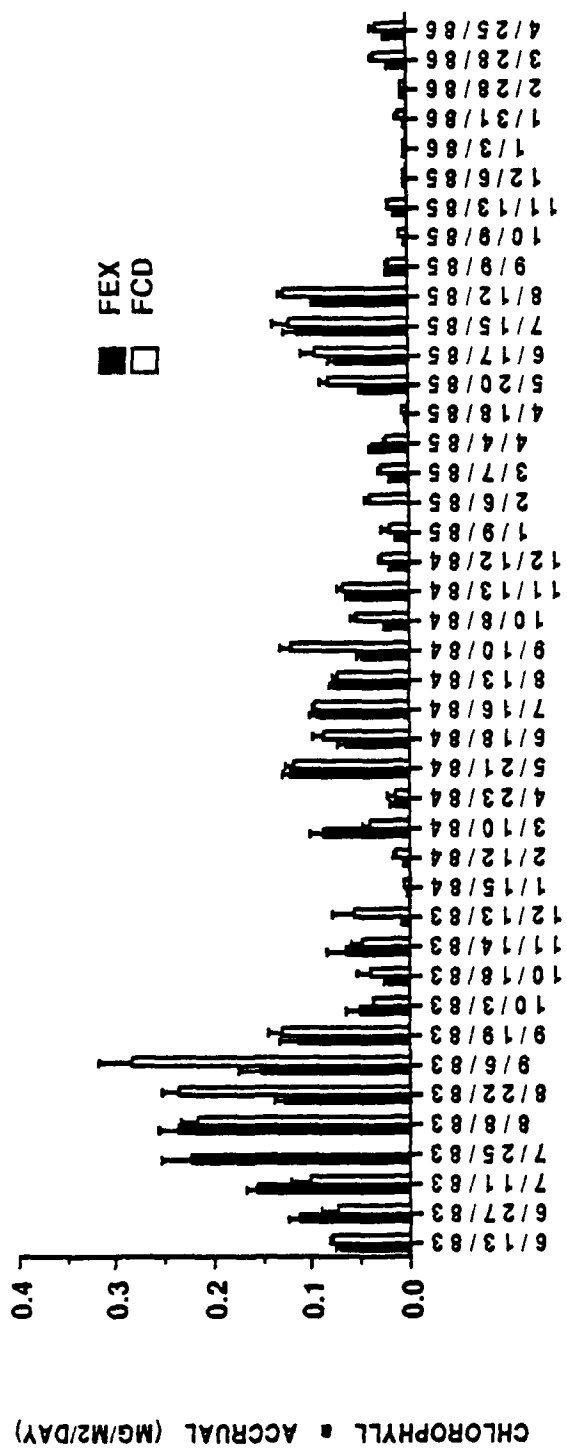


FIGURE 2.2 ACCRUAL RATES OF CHLOROPHYLL  $a$  FOR THE FORD RIVER, 1983-88.

Table 2.5 Daily accrual rates of chlorophyll a ( $\text{mg}/\text{m}^2/\text{d}$ ) and AFDW-Biomass ( $\text{mg}/\text{m}^2/\text{d}$ ) for Control (FCD) and Experimental (FEX) sites on the Ford River. Means  $\pm$  S.E., N in Parentheses.

Date	Chlorophyll a		AFDW - Biomass	
	FCD	FEX	FCD	FEX
10/12/88	0.039 $\pm$ 0.005 (10)	0.050 $\pm$ 0.004 (10)	25.0 $\pm$ 3 (10)	17.0 $\pm$ 1 (10)
12/27/88	0.026 $\pm$ 0.003 (25)	0.044 $\pm$ 0.003 (25)	15.0 $\pm$ 1 (13)	4.0 $\pm$ 1 (15)
2/28/88	0.053 $\pm$ 0.009 (25)	0.020 $\pm$ 0.007 (25)	9.0 $\pm$ 1 (25)	5.0 $\pm$ 1 (25)
5/2/88	0.030 $\pm$ 0.003 (10)	0.130 $\pm$ 0.019 (10)	34.0 $\pm$ 24 (8)	63.0 $\pm$ 29 (8)
5/30/88	0.087 $\pm$ 0.009 (10)	0.076 $\pm$ 0.006 (10)	60.0 $\pm$ 26 (7)	36.0 $\pm$ 13 (7)
6/27/88	0.450 $\pm$ 0.020 (8)	0.653 $\pm$ 0.031 (8)	40.0 $\pm$ 3 (10)	67.0 $\pm$ 2 (10)
7/25/88	0.230 $\pm$ 0.021 (9)	0.681 $\pm$ 0.077 (9)	33.0 $\pm$ 2 (10)	52.0 $\pm$ 3 (10)
8/22/88	0.046 $\pm$ 0.003 (10)	0.046 $\pm$ 0.003 (10)	13.0 $\pm$ 1 (9)	19.0 $\pm$ 3 (9)

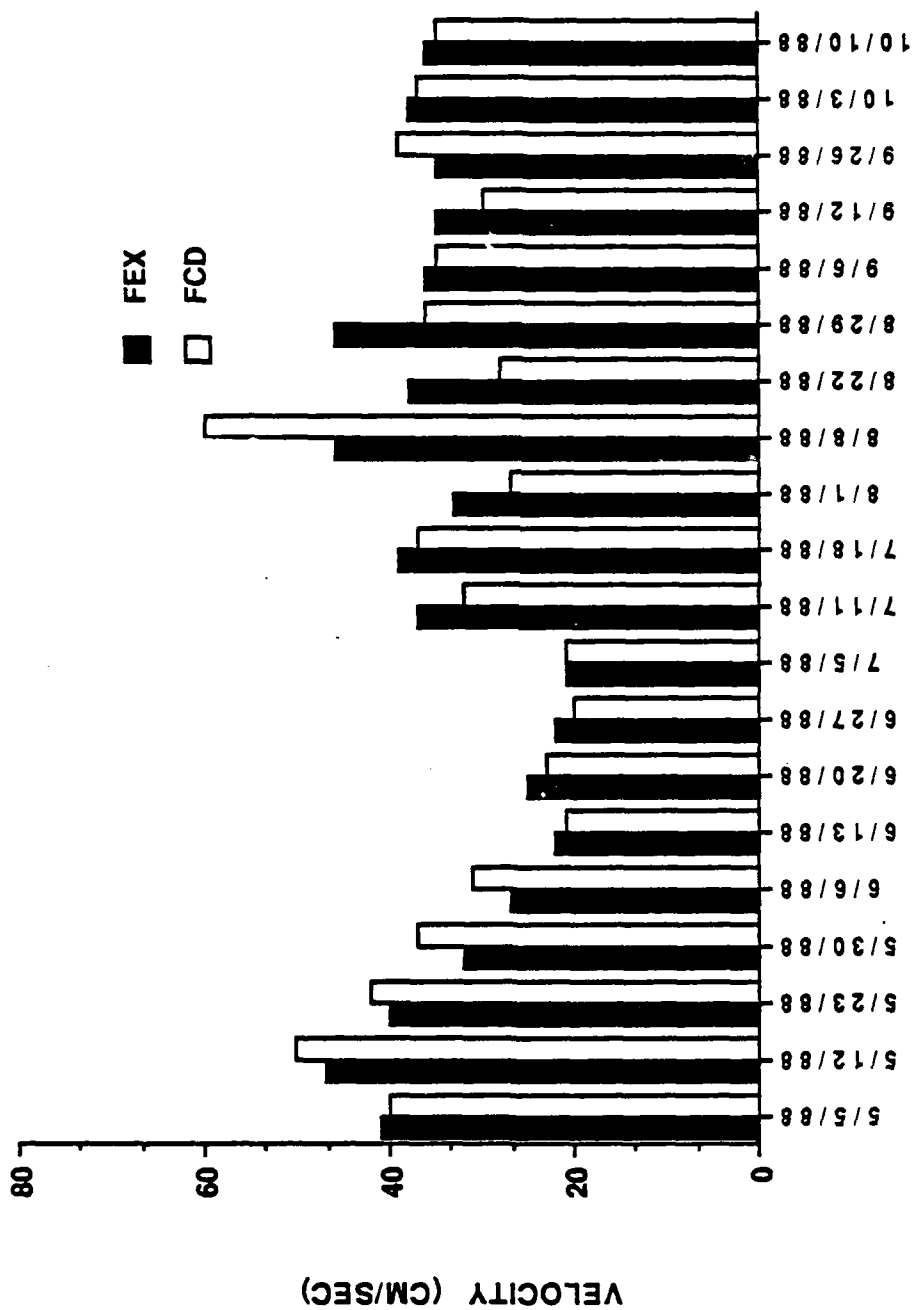


FIGURE 2.3 WATER VELOCITIES AT PERIPHYTON SAMPLERS FOR 1988.

significant site differences in the last four years. BACI analysis for chlorophyll *a* accrual rate data will be included in the 1989 annual report to compare site differences since the start of the study.

### C. Patterns of Organic Matter Accumulation

Organic matter measured as accumulation of ash free dry weight (AFDW) on glass slides generally followed the same trends in 1987-1988 as did chlorophyll *a* (Figs. 2.1, 2.4). The organic matter standing crop peaked in May (1260-1650 mg m<sup>-2</sup>) and remained high throughout the summer (Table 2.6). The pattern for the colder winter months was essentially the same for 1987 as for the previous four winter periods.

Paired t-tests between sites for AFDW-organic matter accumulation showed no significant differences for 1987-1988 data (Table 2.2) or for all the data taken since 1983 (Table 2.3). Correlations between both sites (Table 2.2) showed a non-significant correlation coefficient ( $r=.55$ ) in 1988 despite the fact that AFDW-organic matter between the two sites was significantly correlated when the entire period from 1983 to 1988 was considered. BACI analyses were conducted on AFDW-organic matter standing crop data (Table 2.7). The overall 5.5 year lumped comparison for AFDW mean differences for the 1983-86 "before" and 1986-88 "after" and the winter comparisons (83-85 vs. 86-88) were both found to be non-significant. The summer AFDW data for the "before" period of 1983-1985 was not additive, so the t-test, therefore, was invalid.

Like chlorophyll *a*, AFDW-organic matter accumulation was positively, significantly ( $p<.01$ ) correlated with water temperature ( $r=0.56$  and  $0.46$  for FEX and FCD respectively) and negatively correlated with discharge ( $-0.38$  and  $-0.51$  for FEX and FCD). It was also positively correlated with pH ( $0.57$  and  $0.44$  for FEX and FCD) and chlorophyll *a* as discussed above. It was also negatively correlated with nitrate-N and inorganic-N ( $r=-0.36$  to  $-0.42$ ). Unlike chlorophyll, it was not correlated with conductivity, alkalinity, cell density, or species diversity.

Organic matter accrual rates (Table 2.5 and Fig. 2.5) showed high variability and overall agreement between sites for long term data, but there were major differences between sites for certain dates. Despite the major differences between sites for several months, there were no significant differences between sites for 1987-1988 (Table 2.2). A BACI analysis of organic matter accrual rates will be included in next year's annual report in addition to the paired t-test.



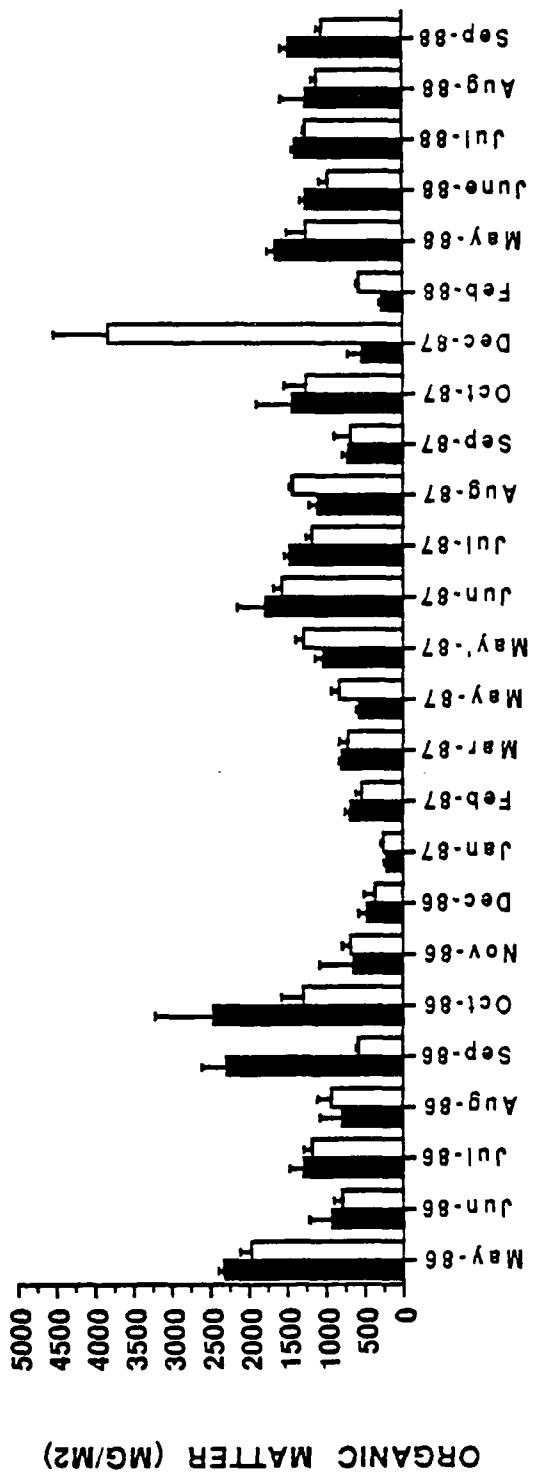
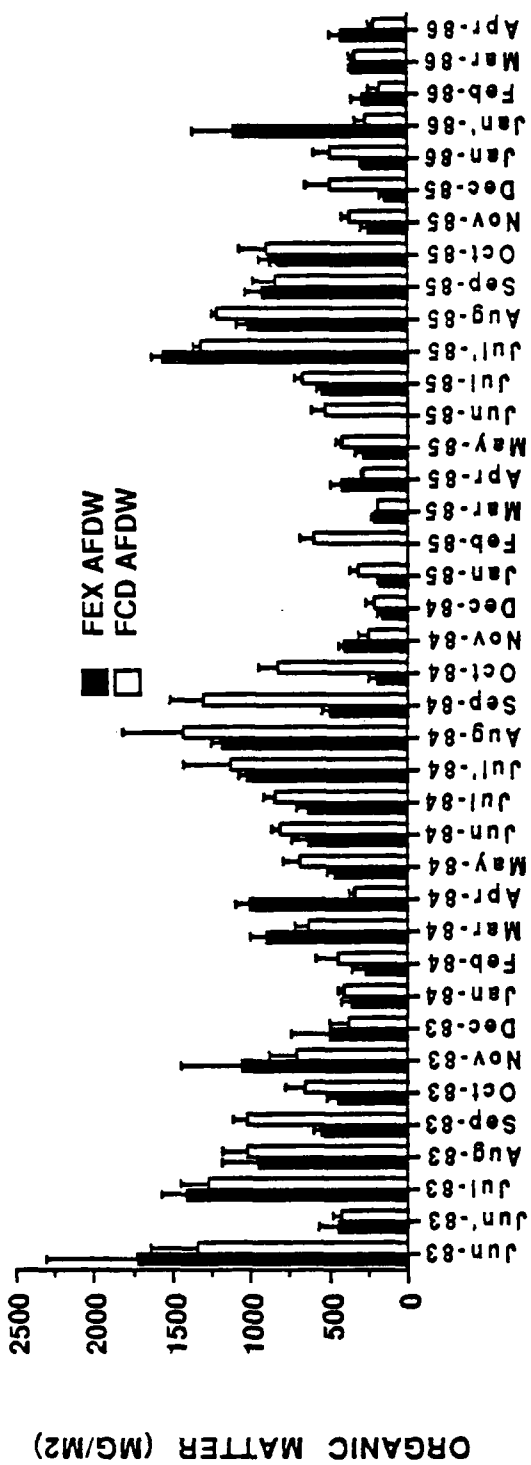


FIGURE 2.4 ORGANIC MATTER STANDING CROP FOR THE FORD RIVER, 1983-88.

Table 2.6 Ash Free Dry Weight Biomass (mg/m<sup>2</sup>) from slides exposed for 28 days in The Ford River (means  $\pm$  S.E., N in parentheses).

<u>Date Out</u>	<u>Control Site (FCD)</u>	<u>Experimental Site (FEX)</u>
10/26/87	1,540 $\pm$ 60 (7)	940 $\pm$ 60 (6)
12/27/87*	920 $\pm$ 70 (13)	240 $\pm$ 50 (15)
2/28/88*	570 $\pm$ 30 (25)	290 $\pm$ 30 (25)
5/16/88**	1,260 $\pm$ 250 (10)	1,650 $\pm$ 110 (10)
6/13/88	950 $\pm$ 120 (8)	1,260 $\pm$ 50 (8)
7/11/88	1,250 $\pm$ 30 (10)	1,410 $\pm$ 30 (10)
8/8/88	1,110 $\pm$ 80 (10)	1,260 $\pm$ 310 (10)
9/6/88	1,020 $\pm$ 70 (10)	1,470 $\pm$ 110 (10)

\* Due to the change in the winter sampling schedule, the data for 12/27/87 is from slides that had been exposed for 63 days and the slides for 2/28/88 had been exposed for 62 days.

\*\* The slides that were to be picked up in April were lost in the river, therefore, the next data set is the 28 day slides from May.

Table 2.7 Results of BACI Comparisons of AFDW-Biomass between Control (FCD) and Experimental (FEX) Sites, 1983-88.

Comparison: (Bel/Aft, Bel/Bel, or Aft/Aft)	DF	Tukey's Test for Additivity*			t-test*					
		BEFORE Prob.	Sig. p < 0.05	DF	AFTER Prob.	Sig. p < 0.05	DF	Unpaired t-value	Probability (two-tailed) p < 0.05	Sig.
6/83-4/86 //	38	0.350	NS	24	0.047	S	62	-0.924	0.359	NS
S 83-85/86-88	19	0.027	S	16	0.548	NS	35	-2.823	0.007	S
S 83/84	5	0.296	NS	6	0.071	NS	11	1.699	0.117	NS
S 83/85	5	0.296	NS	6	0.314	NS	11	-0.620	0.548	NS
S 83/86	5	0.296	NS	5	0.760	NS	10	-1.871	0.091	NS
S 83/87	5	0.296	NS	5	0.931	NS	10	-0.098	0.924	NS
S 83/88	5	0.296	NS	4	0.861	NS	9	-2.225	0.053	NS
S 84/85	6	0.071	NS	6	0.314	NS	12	-2.402	0.033	NS
S 84/86	6	0.071	NS	5	0.760	NS	11	-3.100	0.010	S
S 84/87	6	0.071	NS	5	0.931	NS	11	-1.871	0.088	NS
S 84/88	6	0.071	NS	4	0.861	NS	10	-3.358	0.007	S
S 85/86	6	0.314	NS	5	0.760	NS	11	-1.661	0.125	NS
S 85/87	6	0.314	NS	5	0.931	NS	11	0.580	0.573	NS
S 85/88	6	0.314	NS	4	0.861	NS	10	-1.900	0.087	NS
S 86/87	5	0.760	NS	5	0.931	NS	10	1.899	0.087	NS
S 86/88	5	0.760	NS	4	0.861	NS	9	0.590	0.570	NS
S 87/88	5	0.931	NS	4	0.761	NS	9	-2.597	0.029	S
W 83-85/86-87	18	0.056	NS	7	0.795	NS	25	1.042	0.307	NS
W 83/84	5	0.200	NS	5	0.882	NS	10	1.216	0.252	NS
W 83/85	5	0.200	NS	6	0.246	NS	11	0.471	0.647	NS
W 83/86	5	0.200	NS	5	0.834	NS	10	0.974	0.353	NS
W 83/87	5	0.200	NS	1	-	-	6	2.861	0.029	S
W 84/85	5	0.882	NS	6	0.246	NS	11	-0.505	0.624	NS
W 84/86	5	0.882	NS	5	0.834	NS	10	-0.643	0.535	NS
W 84/87	5	0.882	NS	1	-	-	6	1.686	0.143	NS
W 85/86	6	0.246	NS	5	0.834	NS	11	0.111	0.914	NS
W 85/87	6	0.246	NS	1	-	-	7	1.574	0.160	NS
W 86/87	5	0.834	NS	1	-	-	6	4.262	0.005	S

\*Data was log (x+1) transformed

#### D. Patterns of the Ratio of Chlorophyll a to Phaeophytin a

The ratio of chlorophyll a pigment to its primary degradation product, phaeophytin a was determined every 28 days, (62 days during winter 1987), as part of the routine analysis of chlorophyll a and to determine the physiological health of the algal community (APHA 1980). This ratio was less variable for 1987-88 (Table 2.8) than it had been in previous years (see previous annual reports). Because of the apparently random high variability obtained with this index in the past, it will probably not be very useful for comparing ELF effects between the experimental and control sites. Paired t-tests between sites for 1987-88 showed no significant differences (Table 2.2).

#### E. Patterns of Diatom Cell Density

Diatom cell density was characterized by wintertime low levels for each of the years studied at each site (Fig. 2.6). Typically, the lowest values occurred in January or February when the Ford River was ice covered and limited light penetration and water temperatures likely reduced the rate of photosynthesis and subsequent cell growth. The wintertime season, stretching from late October until April or even May, was a period characterized by diminished levels of periphyton production in terms of diatom density. Actual values ranged from  $10^7$  to  $10^8$  cells per square meter. The greatest periods of diatom production, as measured by cell density, were more sporadic and less predictable. The periods of highest cell density appeared to be most affected by the variations of climatic or environmental conditions or hydrologic changes. The highest monthly densities of cells were reported in August of 1983, June 1984, June 1985, May 1986, May 1987, and May 1988 (Fig. 2.6). Thus, the highest cell densities measured were found to occur anytime within a four month spring-summer period. The duration of continued high cell densities also varied by year (Fig. 2.6), sometimes continuing throughout the summer and at other times restricted to only one or two months of very high densities, e.g., May 1986. In 1988, this peak density was for early May ( $> 92 \times 10^8$  cells per square meter, Table 2.9), and was followed by a gradual decline in diatom densities throughout the summer and fall (Fig. 2.6). Although cell densities declined throughout the summer, values remained uncharacteristically high until September in response to the hot, low flow conditions during summer 1988. Thus, it appears that the most predictable pattern was for lowest cell densities in the winter and for greatest densities in the spring and/or summer (Fig. 2.6, Table 2.9).

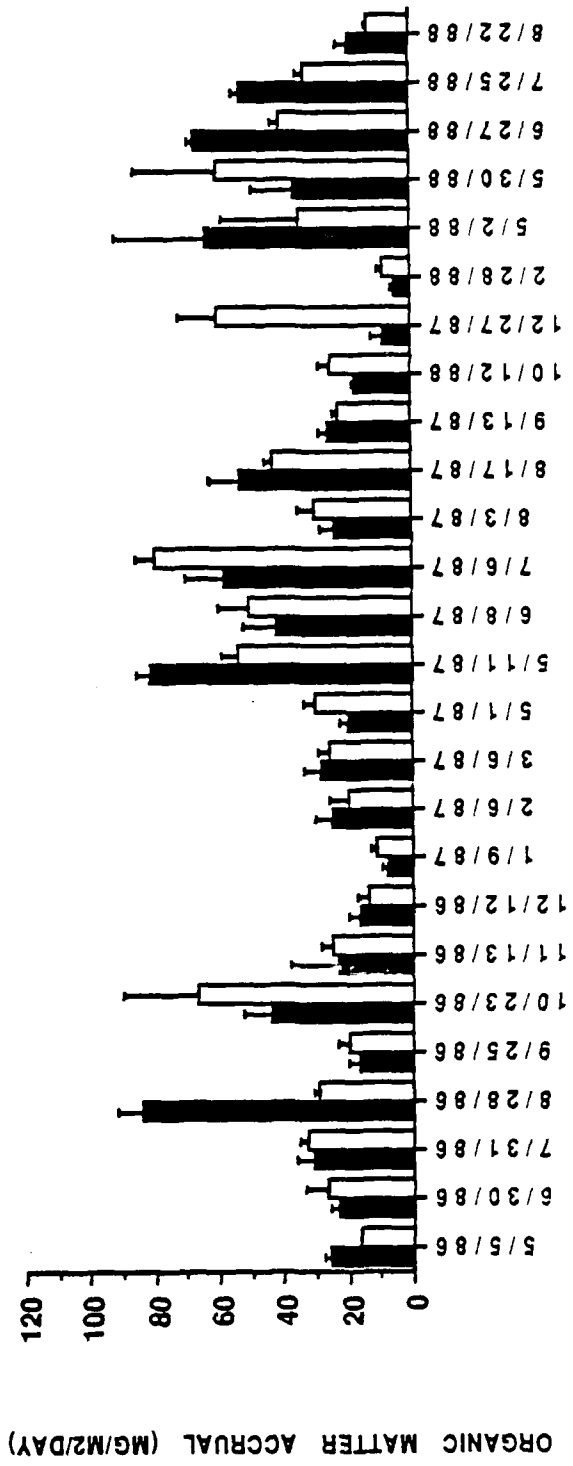
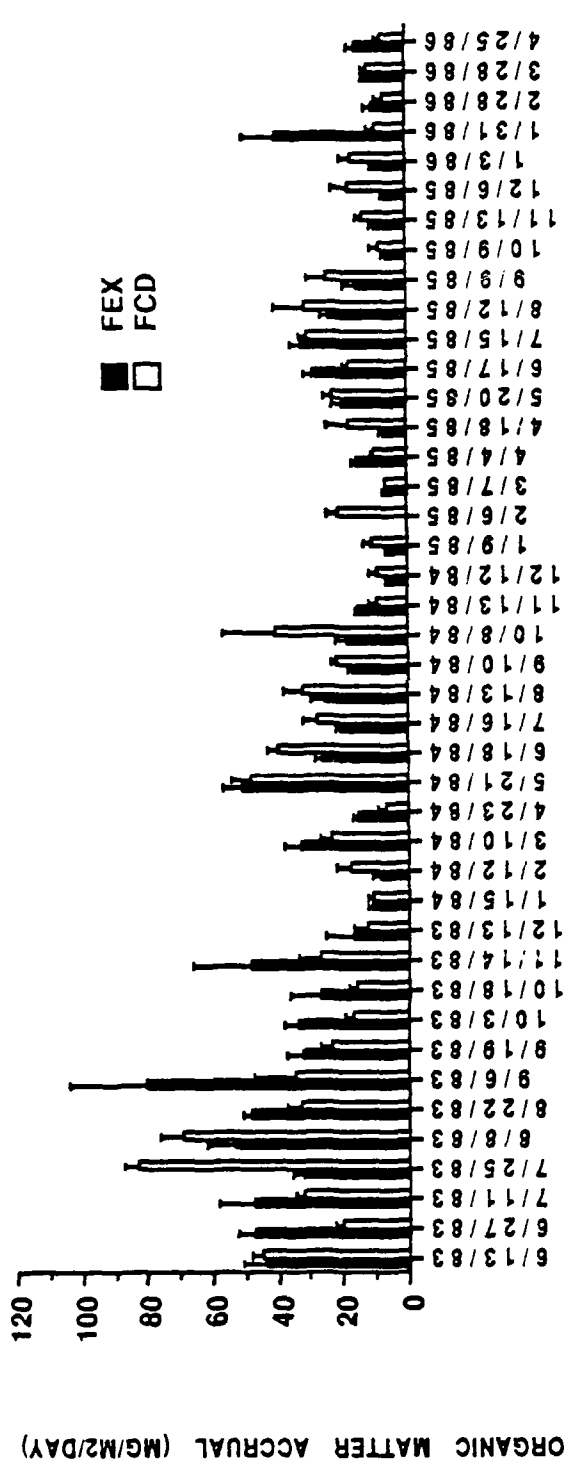
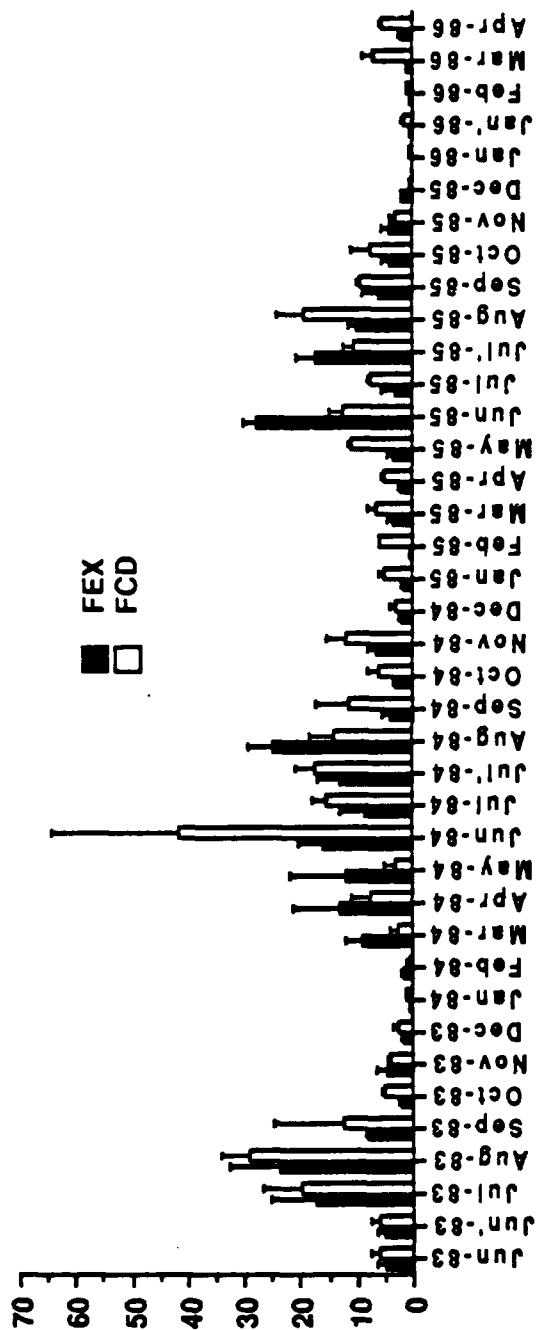


FIGURE 2.5 ACCRUAL RATES OF ORGANIC BIOMASS FOR THE FORD RIVER, 1983-88.

Table 2.8 Chlorophyll a to phaeophytin a ratios from slides exposed 28 days in The Ford River. Means  $\pm$  S.E., N in parentheses.

<u>Date out</u>	<u>Control Site (FCD)</u>	<u>Experimental Site (FEX)</u>
10/26/87	8.62 $\pm$ 1.55 (10)	22.22 $\pm$ 8.93 (10)
12/27/87	15.56 $\pm$ 6.38 (25)	11.37 $\pm$ 3.52 (25)
2/28/88	15.74 $\pm$ 5.01 (21)	11.99 $\pm$ 3.43 (21)
5/16/88	7.89 $\pm$ 2.75 (9)	6.90 $\pm$ 4.29 (9)
6/13/88	3.26 $\pm$ 0.50 (10)	5.89 $\pm$ 0.72 (10)
7/11/88	3.53 $\pm$ 0.99 (9)	7.92 $\pm$ 5.77 (9)
8/8/88	9.55 $\pm$ 2.16 (8)	8.17 $\pm$ 2.67 (8)
9/6/88	5.76 $\pm$ 0.60 (9)	7.87 $\pm$ 1.31 (9)

DIATOM DENSITY (NUMBERS/M<sup>2</sup> • 10e8)



DIATOM DENSITY (NUMBERS/M<sup>2</sup> • 10e8)

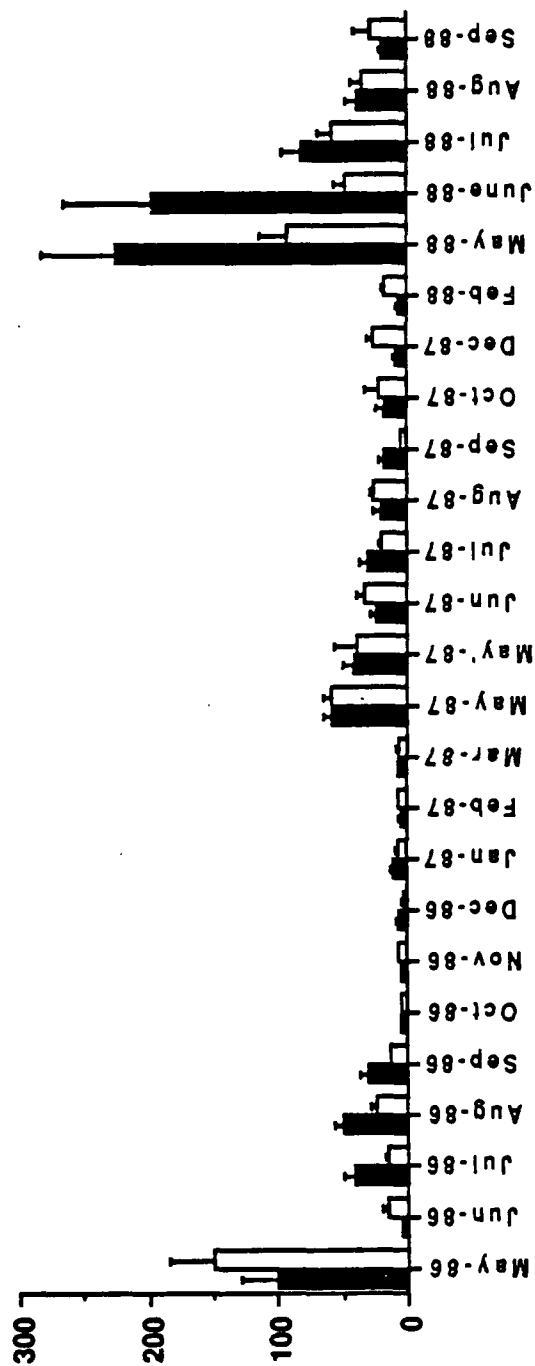


FIGURE 2.6 DIATOM CELL DENSITIES FOR THE FORD RIVER, 1983-88.

Table 2.9 Cell Density (cells/m<sup>2</sup> x 10<sup>8</sup>) and Biovolume (cubic microns/m<sup>2</sup> x 10<sup>11</sup>) for experimental (FEX) and Control (FCD) sites for 1987-1988. Data are means  $\pm$  S.E., N=3 except for 12/27 and 2/28 when N=6.

Date	Experimental (FEX)		Control (FCD)	
	Density	Biovolume	Density	Biovolume
10/26/87	17.74 $\pm$ 4.76	4.63 $\pm$ 2.78	21.82 $\pm$ 10.70	5.04 $\pm$ 2.30
12/27/87	8.32 $\pm$ 1.57	1.83 $\pm$ 0.34	25.01 $\pm$ 3.92	6.31 $\pm$ 1.42
2/28/88	7.06 $\pm$ 1.21	1.67 $\pm$ 0.34	16.76 $\pm$ 3.45	3.60 $\pm$ 0.61
5/16/88	224.45 $\pm$ 57.52	44.65 $\pm$ 8.34	91.56 $\pm$ 21.68	15.12 $\pm$ 4.40
6/13/88	197.79 $\pm$ 67.75	42.12 $\pm$ 13.94	46.69 $\pm$ 8.00	9.72 $\pm$ 0.64
7/11/88	81.60 $\pm$ 13.91	16.50 $\pm$ 3.52	58.54 $\pm$ 11.10	15.07 $\pm$ 5.95
8/8/88	39.04 $\pm$ 8.94	8.82 $\pm$ 1.81	34.05 $\pm$ 9.48	7.66 $\pm$ 1.54
9/6/88	18.62 $\pm$ 2.06	4.21 $\pm$ 0.52	28.77 $\pm$ 10.95	7.20 $\pm$ 2.89



As with chlorophyll *a* and AFDW-organic matter accumulation, cell density was significantly ( $p < 0.05$ ), positively correlated with water temperature ( $r = 0.44$  and  $0.46$  for FEX and FCD respectively). Unlike chlorophyll and organic matter, however, there was no correlation with discharge. Density was negatively correlated with dissolved oxygen ( $r = -0.44$  and  $-0.38$  for FEX and FCD respectively). Cell density was significantly, positively correlated with chlorophyll *a* as discussed earlier and negatively correlated with evenness ( $-0.58$  and  $-0.56$  for FEX and FCD) and diversity ( $r = -0.51$  and  $-0.38$ ).

In spite of the apparent high variability between years, paired *t* tests showed that site differences in cell densities were not significant for 1987-88 (Table 2.2) or for all the data collected since 1983 (Table 2.3). Cell density for the two sites was also closely correlated (Tables 2.2, 2.3). BACI results from the overall 5.5 year cell density data, however, showed a significant difference between "before" (6/83-4/86) and "after" (5/86-9/88) periods (Table 2.10). Further analysis suggested that the summer variations was responsible for this significant result. Although both the "before" and "after" log ( $x+1$ ) transformed data were additive, we suspect that the greater impact of the 1988 drought at FEX did cause the significance. Individual comparisons of mean differences for S 83/88, S 84/88, and S 85/88, all involving this year's data, were either significant ( $p < .05$ ), or close to being significantly different (Table 2.10).

#### F. Patterns in Individual Cell Volume and Total Biovolume

Individual cell volumes for the five year period (Fig. 2.7) were characterized by a trend towards larger volumes of diatoms in the periphyton occurring during the colder, winter months of November through March and smaller diatoms occurring during the summer months. The 1987-88 cell volume data did not follow this pattern however. Following the dramatic rise in mean cell volume during the winter of 1986 associated with dominance by *Synedra* and *Diatoma*, values dropped off during the spring-summer and did not increase over winter 1987 as they had done in the past (Fig. 2.7, Table 2.11). These differences were related to differences in dominance for the algal community as will be described in detail below.

Table 2.10 Results of BACI Comparisons of Cell Density between Control (FCD) and Experimental (FEX) Sites, 1983-88.

Comparison: (Bef/Alt, Bef/Bef, or Alt/Alt)		Tukey's Test for Additivity*				t-test*				
	DF	BEFORE Prob.	Sig. p < 0.05	DF	AFTER Prob.	Sig. p < 0.05	DF	Unpaired t-value	Probability (two-tailed)	Sig. p < 0.05
6/83-4/86 // 5/86-9/88	38	0.203	NS	24	0.063	NS	62	-2.231	0.029	S
S 83-85/86-88	19	0.262	NS	16	0.714	NS	35	-2.442	0.020	S
S 83/84	5	0.229	NS	6	0.803	NS	11	-0.294	0.774	NS
S 83/85	5	0.229	NS	6	0.031	S	11	0.014	0.989	NS
S 83/86	5	0.229	NS	5	0.720	NS	10	-1.305	0.221	NS
S 83/87	5	0.229	NS	5	0.837	NS	10	-1.787	0.104	NS
S 83/88	5	0.229	NS	4	0.057	NS	9	-2.630	0.027	S
S 84/85	6	0.803	NS	6	0.031	S	12	0.268	0.794	NS
S 84/86	6	0.803	NS	5	0.720	NS	11	-0.769	0.458	NS
S 84/87	6	0.803	NS	5	0.837	NS	11	-0.907	0.384	NS
S 84/88	6	0.803	NS	4	0.057	NS	10	-1.460	0.175	NS
S 85/86	6	0.031	S	5	0.720	NS	11	-1.115	0.289	NS
S 85/87	6	0.031	S	5	0.837	NS	11	-1.343	0.206	NS
S 85/88	6	0.031	S	4	0.057	NS	10	-1.954	0.079	NS
S 86/87	5	0.720	NS	5	0.837	NS	10	-0.042	0.967	NS
S 86/88	5	0.720	NS	4	0.057	NS	9	-0.662	0.525	NS
S 87/88	5	0.837	NS	4	0.057	NS	9	-0.748	0.474	NS
W 83-85/86-87	18	0.654	NS	7	0.086	NS	25	-0.501	0.620	NS
W 83/84	5	0.242	NS	5	0.216	NS	10	2.608	0.026	S
W 83/85	5	0.242	NS	6	0.903	NS	11	1.381	0.195	NS
W 83/86	5	0.242	NS	5	0.779	NS	10	0.191	0.852	NS
W 83/87	5	0.242	NS	1	-	-	6	2.527	0.045	S
W 84/85	5	0.216	NS	6	0.903	NS	11	0.699	0.499	NS
W 84/86	5	0.216	NS	5	0.779	NS	10	-3.096	0.011	S
W 84/87	5	0.216	NS	1	-	-	6	0.744	0.485	NS
W 85/86	6	0.903	NS	5	0.779	NS	11	-1.399	0.189	NS
W 85/87	6	0.903	NS	1	-	-	7	0.928	0.384	NS
W 86/87	5	0.779	NS	1	-	-	6	3.966	0.007	S

\*Data was log(x+1) transformed

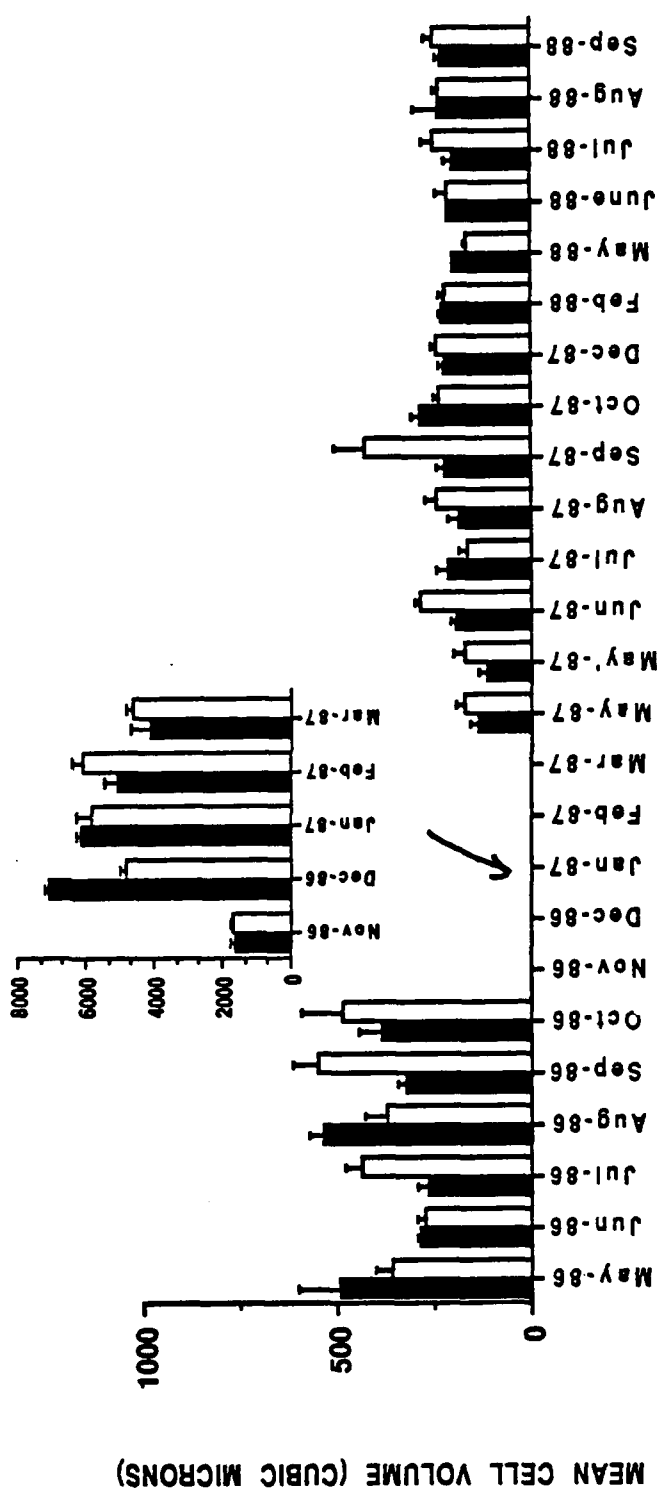
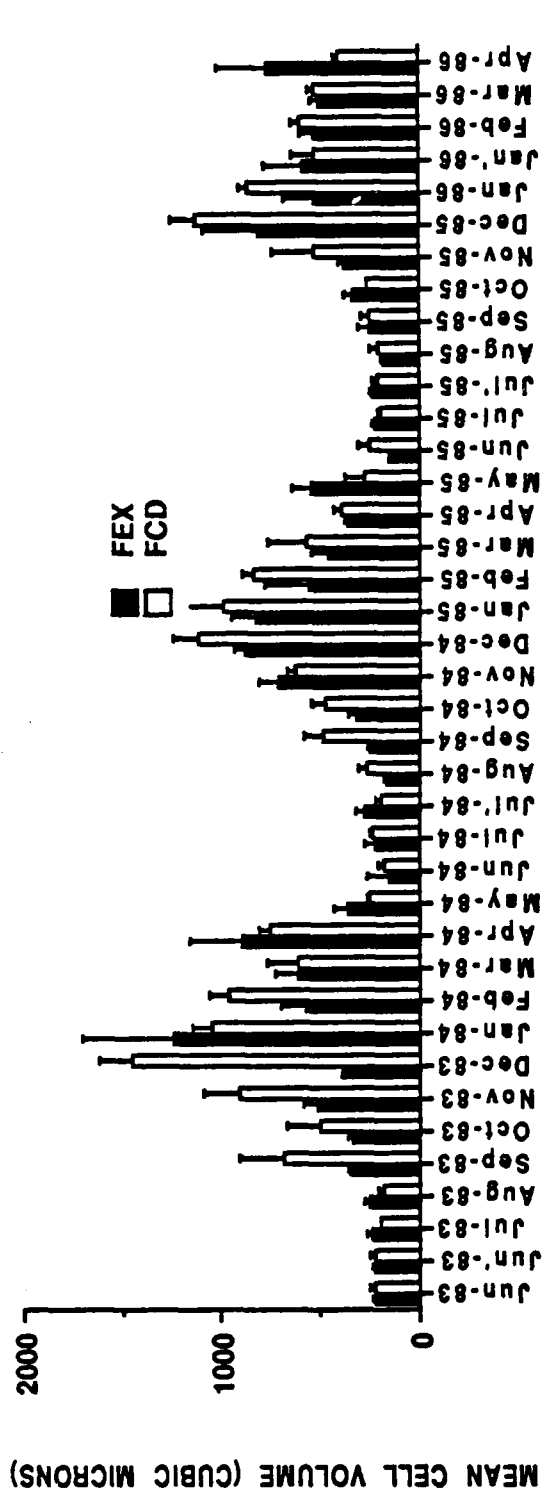


FIGURE 2.7 INDIVIDUAL CELL SIZES FOR THE FORD RIVER, 1983-88.

Table 2.11 Average Individual Diatom Cell Volume (microns<sup>3</sup>) for Experimental (FEX) and Control (FCD) sites for 1987-88. Data are means  $\pm$  S.E., N = 3 except for 12/27 and 2/28 when N = 6.

Date	Experimental (FEX)	Control (FCD)
10/26/87	283.32 $\pm$ 24.96	238.19 $\pm$ 9.41
12/27/87	223.11 $\pm$ 9.98	239.86 $\pm$ 20.13
2/28/88	231.47 $\pm$ 6.55	223.19 $\pm$ 11.80
5/16/88	198.01 $\pm$ 3.09	162.05 $\pm$ 8.71
6/13/88	214.04 $\pm$ 2.66	217.84 $\pm$ 28.38
7/11/88	201.04 $\pm$ 17.01	252.72 $\pm$ 23.88
8/8/88	238.91 $\pm$ 60.16	234.00 $\pm$ 18.35
9/6/88	226.57 $\pm$ 15.42	250.10 $\pm$ 18.76

A paired t-test showed that mean cell volume was not significantly different between sites (Table 2.2) for either 1987-88 or all data collected since 1983 (Table 2.3). Mean cell volume at FEX in 1988 was not significantly correlated with mean cell volume at FCD (Table 2.2) despite the fact that they were highly correlated when all data collected since 1983 were considered (Table 2.3). BACI comparisons of cell volume showed that "before" data were not different from "after" data either on an overall basis or for any summer or winter season comparisons (Table 2.12). However, since the "before" data was not additive for most of these comparisons (Table 2.12), the t-test cannot be considered valid (Stewart-Oaten 1986).

Cell volume was significantly ( $p < 0.01$ ), negatively correlated with water temperature. This was the only significant correlation found with any of the physical or chemical parameters monitored (see Element 1). Cell volume was negatively correlated with both diversity and evenness ( $r = -0.35$  to  $-0.36$  for all comparisons at FEX and FCD,  $p < 0.01$ ). Of course, it was positively correlated with total algal biovolume since biovolume is calculated from cell density and average cell volume.

Generally, the total biovolume of diatom cells was low for 1987-88, except for the months of May, June and July (Fig. 2.8). This peak corresponded with a similar peak recorded in diatom density for the same period (Fig. 2.6, Table 2.9). In fact, both density (Fig. 2.6) and biovolume (Fig. 2.8) have been characterized by substantially larger spring-summer peak values since May 1986, apparently as a result of the very dry months of May since that time. The large biovolume peak observed during the 1986-87 winter was not repeated in 1987-88 due to the absence of the large species, Synedra ulna. The low densities, combined with low average cell volumes produced more normal biovolumes for the winter of 1987-88 (Fig. 2.8).

A comparison of total biovolume between sites with the paired t-test showed that biovolume at FEX was not significantly different ( $p < 0.05$ ) from biovolume at FCD either for the 1987-88 data (Table 2.2) or for all data collected since 1983 (Table 2.3). Biovolume at FEX was significantly ( $p < 0.05$ ) correlated with biovolume at FCD both in 1987-88 (Table 2.2) and for all the data collected since 1983 (Table 2.3). BACI comparisons of biovolume at FEX and biovolume at FCD "before" and "after" May 1986 showed that the transformed biovolume "after" data for 1986-1988 were not additive (Table

Table 2.12 Results of BACI Comparisons of Cell Volume between Control (FCD) and Experimental (FEX) Sites, 1983-88.

Comparison:		Tukey's Test for Additivity*				t-test†		
(Bel/Aft, Bef/Bef, or Aft/Aft)	DF	BEFORE Prob.	Sig. p < 0.05	DF	AFTER Prob.	Sig. p < 0.05	Unpaired t-value	Probability (two-tailed) p < 0.05
6/83-4/86 //	38	0.022	S	24	0.182	NS	-1.035	0.305
5/86-9/88	19	0.092	NS	16	0.774	NS	0.223	0.824
S 83-85/86-88	5	0.001	S	6	0.278	NS	-0.255	0.803
S 83/84	5	0.001	S	6	0.001	S	-1.355	0.203
S 83/85	5	0.001	S	5	0.848	NS	-0.368	0.720
S 83/86	5	0.001	S	5	0.279	NS	-0.169	0.869
S 83/87	5	0.001	S	4	0.197	NS	-0.822	0.433
S 83/88	6	0.278	NS	6	0.001	S	-1.247	0.236
S 84/85	6	0.278	NS	5	0.848	NS	-0.170	0.868
S 84/86	6	0.278	NS	5	0.279	NS	0.118	0.908
S 84/87	6	0.278	NS	4	0.197	NS	-0.643	0.534
S 84/88	6	0.001	S	5	0.848	NS	0.877	0.399
S 85/86	6	0.001	S	5	0.279	NS	1.502	0.161
S 85/87	6	0.001	S	4	0.197	NS	0.803	0.441
S 85/88	5	0.848	NS	5	0.279	NS	0.276	0.788
S 86/87	5	0.848	NS	4	0.197	NS	-0.331	0.748
S 86/88	5	0.279	NS	4	0.197	NS	-1.022	0.333
S 87/88	18	0.285	NS	7	0.554	NS	-1.128	0.270
W 83-85/86-87	5	0.872	NS	5	0.288	NS	-0.645	0.534
W 83/84	5	0.872	NS	6	0.272	NS	-0.911	0.382
W 83/85	5	0.872	NS	5	0.630	NS	-0.844	0.418
W 83/86	5	0.872	NS	1	-	-	-0.704	0.508
W 83/87	5	0.288	NS	6	0.272	NS	-0.502	0.626
W 84/85	5	0.288	NS	5	0.630	NS	-0.633	0.541
W 84/86	5	0.288	NS	1	-	-	-1.188	0.280
W 84/87	6	0.272	NS	5	0.630	NS	-0.550	0.593
W 85/86	6	0.272	NS	1	-	-	-0.359	0.730
W 85/87	5	0.630	NS	1	-	-	0.210	0.841

\*Data was not transformed

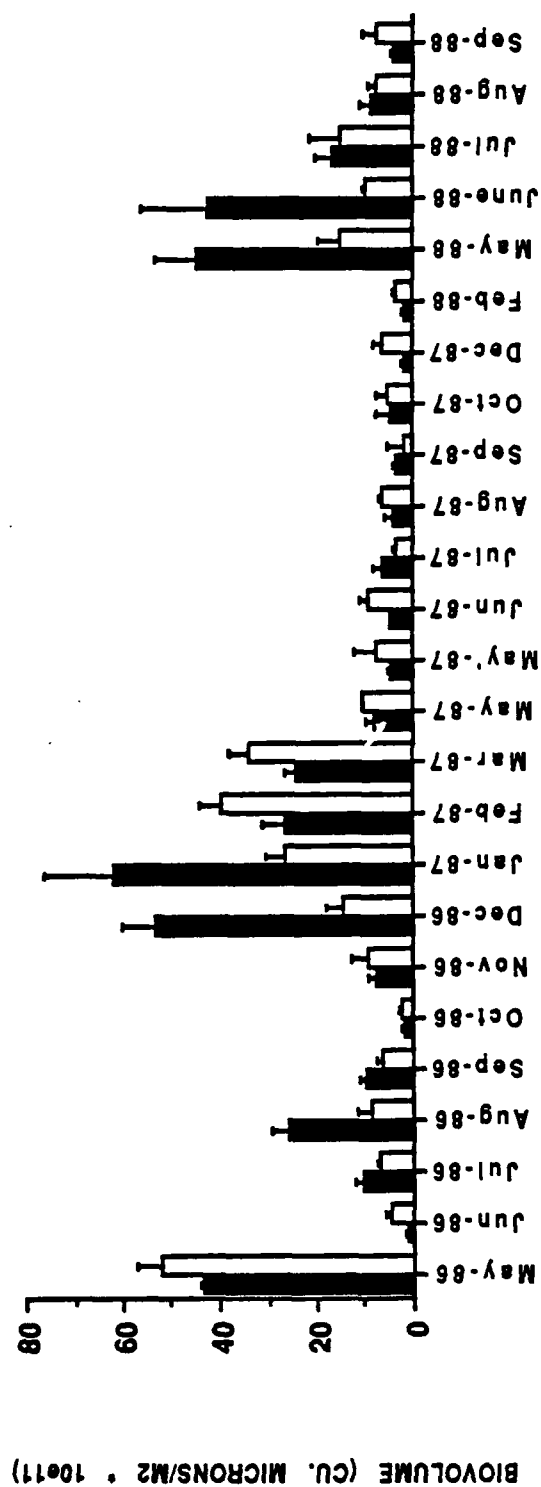
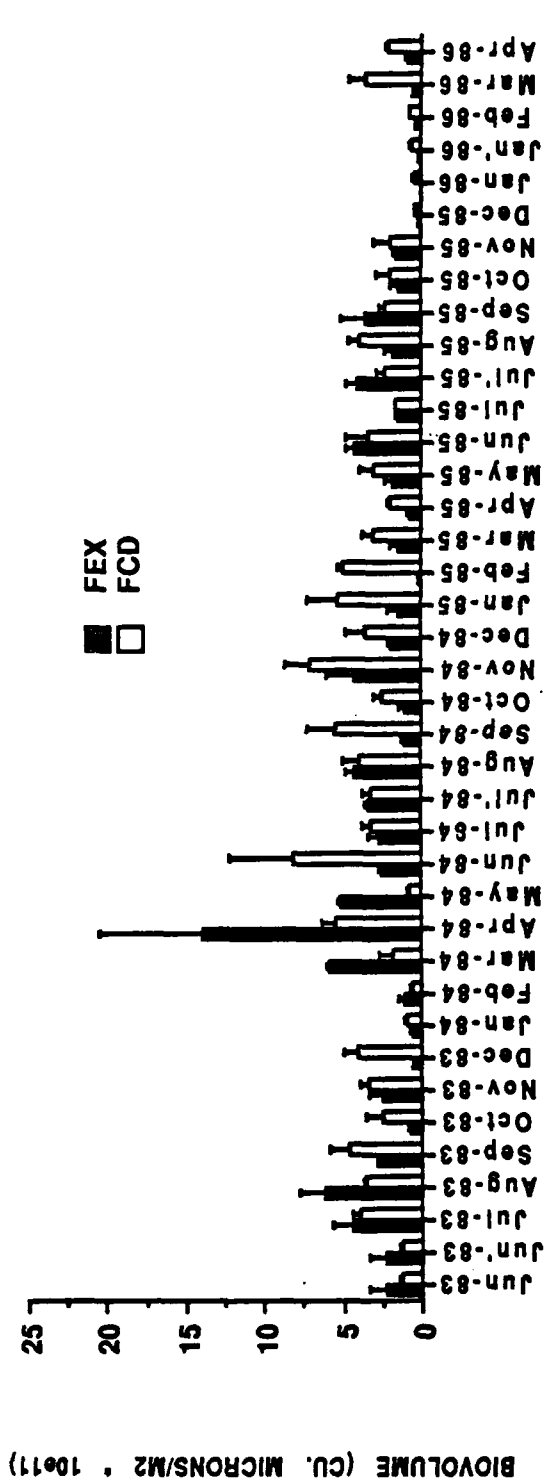


FIGURE 2.8 DIATOM BIOVOLUME FOR THE FORD RIVER, 1983-88.

2.13). However, the t-test showed no significant difference in the means of the "before" and "after" data. Summer and winter lumped comparisons of biovolume using the BACI procedure also demonstrated that there were no differences between the sites in the data collected before and after testing of the ELF system began in 1986 (Table 2.13).

Correlations of total algal biovolume with all the physical and chemical parameters monitored (see Element 1) resulted in no significant ( $p < 0.05$ ) correlations except for negative correlations with cumulative rainfall ( $r = -0.31$  for both sites) and maximum rainfall amounts ( $r = -0.36$  for both sites) as well as days with rain amounts of 12.5 mm or more ( $r = -0.29$  and  $-0.28$  for FEX and FCD) and a positive correlation with days since the last rain ( $r = 0.27$  and  $0.28$  for FEX and FCD). The correlations of rain with average cell volume have the same level of significance and are of the same magnitude as for total biovolume. There were no significant correlations of these parameters with density. Thus, increases in average cell volume after runoff events seemed to be driving these correlations. Interestingly, these rainfall parameters were not correlated with chlorophyll *a*, AFDW-organic matter accumulation, or evenness but were partially correlated with diversity in the reverse direction, i.e. positive correlations with cumulative rainfall ( $r = 0.31$  and  $0.41$  for FEX and FCD respectively) and maximum rainfall ( $r = 0.31$  and  $0.37$  at FEX and FCD). Correlations between diversity and days since the last rain and days with more than 12.5 mm of rain were not significant for FEX but are for FCD ( $r = -0.31$  and  $0.28$  respectively).

Correlations of total algal biovolume with cell density were not significant despite the fact that biovolume is the product of density times average cell volume. Average cell volume was correlated with total biovolume at both FEX and FCD ( $r = 0.66$  and  $0.59$  respectively,  $p < 0.01$ ). Total biovolume was also correlated with chlorophyll *a* ( $r = 0.39$  and  $0.28$  at FEX and FCD respectively,  $p < 0.05$ ) and negatively correlated ( $p < 0.01$ ) with both diversity ( $r = -0.52$  and  $-0.51$  for FEX and FCD respectively) and evenness ( $r = -0.44$  and  $-0.38$  for FEX and FCD).

#### G. Patterns of Species Diversity and Species Evenness

Changes in species community composition may reflect the effects of a host of environmental variables, such as changing light levels, increasing or decreasing water currents, or changing water temperatures that may act individually or synergistically to subtly change the



Table 2.13 Results of BACI Comparisons of Bloovolume between Control (FCD) and Experimental (FEX) Sites, 1983-88.

Comparison: (Bel/Aft, Bel/Bet, or Aft/Aft)		Tukey's Test for Additivity*				i - test*		Sig. p < 0.05	Probability (two-tailed)	Sig. p < 0.05
DF	BEFORE Prob.	Sig. p < 0.05	DF	AFTER Prob.	Unpaired t-value	DF				
6/83-4/86 // 5/86-9/88	38	0.199	NS	24	0.015	62	-1.770	0.082	NS	NS
S 83-85/86-88	19	0.948	NS	16	0.054	35	-1.054	0.299	NS	NS
S 83/84	5	0.640	NS	6	0.593	11	0.602	0.559	NS	NS
S 83/85	5	0.640	NS	6	0.328	11	0.270	0.792	NS	NS
S 83/86	5	0.640	NS	5	0.443	10	-0.178	0.863	NS	NS
S 83/87	5	0.640	NS	5	0.056	10	0.384	0.709	NS	NS
S 83/88	5	0.640	NS	4	0.058	9	-1.112	0.295	NS	NS
S 84/85	6	0.593	NS	6	0.328	12	-0.493	0.631	NS	NS
S 84/86	6	0.593	NS	5	0.443	11	-0.695	0.501	NS	NS
S 84/87	6	0.593	NS	5	0.056	11	0.319	0.755	NS	NS
S 84/88	6	0.593	NS	4	0.058	10	-1.388	0.195	NS	NS
S 85/86	6	0.328	NS	5	0.443	11	-0.428	0.677	NS	NS
S 85/87	6	0.328	NS	5	0.056	11	0.189	0.854	NS	NS
S 85/88	6	0.328	NS	4	0.058	10	-1.476	0.171	NS	NS
S 86/87	5	0.443	NS	5	0.056	10	0.502	0.627	NS	NS
S 86/88	5	0.443	NS	4	0.058	9	-0.850	0.418	NS	NS
S 87/88	5	0.056	NS	4	0.058	9	-1.389	0.198	NS	NS
W 83-85/86-87	18	0.392	NS	7	0.084	25	-1.071	0.294	NS	NS
W 83/84	5	0.276	NS	5	0.552	10	2.048	0.065	NS	NS
W 83/85	5	0.276	NS	6	0.232	11	1.386	0.193	NS	NS
W 83/86	5	0.276	NS	5	0.412	10	-0.241	0.815	NS	NS
W 83/87	5	0.276	NS	1	-	6	1.370	0.220	NS	NS
W 84/85	5	0.552	NS	6	0.232	11	-1.542	0.151	NS	NS
W 84/86	5	0.552	NS	5	0.412	10	-2.607	0.026	S	S
W 84/87	5	0.552	NS	1	-	6	0.032	0.975	NS	NS
W 85/86	6	0.232	NS	5	0.412	11	-1.831	0.094	NS	NS
W 85/87	6	0.232	NS	1	-	7	1.298	0.235	NS	NS
W 86/87	5	0.412	NS	1	-	6	1.689	0.142	NS	NS

\*Data was log (x + 1) transformed

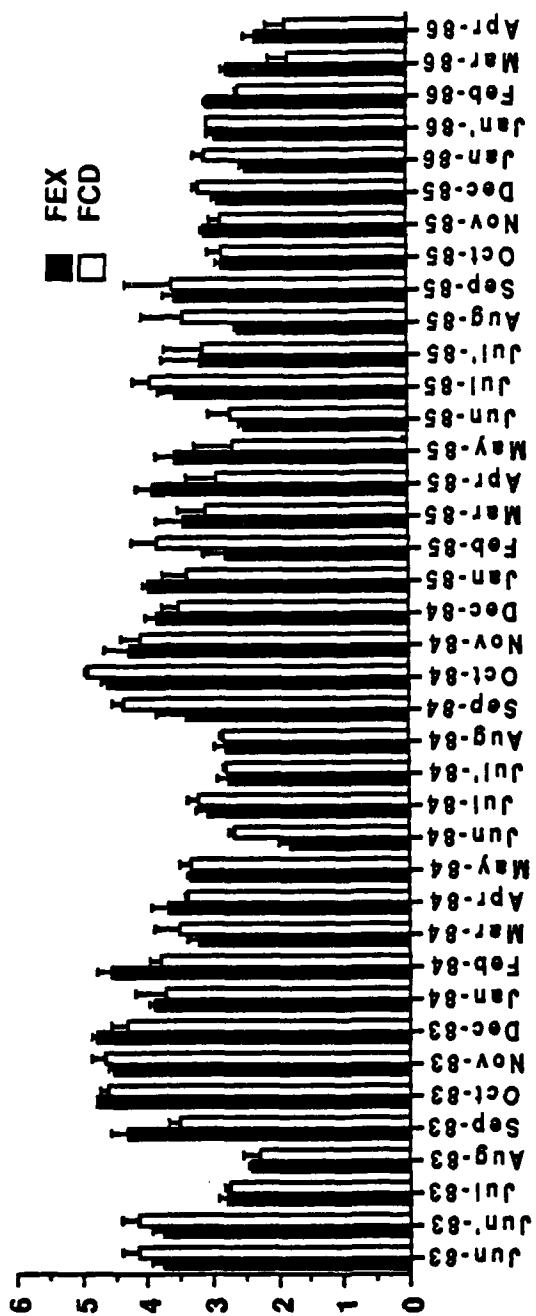
abundance of various algal species. The presence or absence of particular diatom species has been used as an indicator of potential pollution (Patrick 1966). Comparing the changes in the periphyton community through the use of a species diversity index and a species evenness index will measure the extent of changes in number of species and the distribution of individuals within that community. Such indices may indicate potentially subtle shifts in community structure which are often unnoticed using other tests, such as chlorophyll *a* , organic biomass levels, or cell densities.

The pattern in the Shannon Wiener diversity index ( $H'$ ) and the evenness index ( $J'$ ) over the entire period from 1983 to 1988 (Figs. 2.9, 2.10, Table 2.14) was similar, with evenness and diversity appearing to track each other during most seasons. The correlation coefficients between evenness and diversity since the start of the study were 0.72 at FEX and 0.67 at FCD ( $p < 0.01$ ) . In general, the pattern for both indices was that greatest values occurred in the winter months and lowest values in the summer.

The pattern of winter highs and summer lows for diversity and evenness corresponded with predictable patterns in species abundance (Fig. 2.11). During all summers since 1983, only two species groups ever achieved dominance greater than 10 %.(Fig. 2.11). In fact, the two summer species, Achnanthes minutissima (prior to this report, this species has been identified as A. affinis) and Cocconeis placentula (includes several varieties including placentula, euglypta, and lineata), reached summer time highs of 40-60% dominance, and as is discussed in Element 3, appeared to be negatively correlated with each other. The typical pattern was for Achnanthes to be the dominant species in May and June and for its dominance to decrease as Cocconeis dominance increased in July and August and then increase in dominance again in September and October as the abundance of Cocconeis declined.

The winter diatom flora has been much more variable than the summer flora. Achnanthes has been a dominant component of the flora throughout most years, although its dominance in winter usually ranged from only 5 to 20% (Fig. 2.11). Fragilaria vaucheriae has been the next most predictable component of the winter flora followed by Gomphonema olivaceum (Fig. 2.11). Meridion circulare has achieved greater than 10 % dominance in two of the five winters monitored to date (Fig. 2.11), while Diatoma tenue, Gomphonema intricatum, Navicula cryptocephala, and Synedra ulna have only achieved greater than 10 % dominance in one of

SHANNON-WIENER DIVERSITY (H')



SHANNON-WIENER DIVERSITY (H')

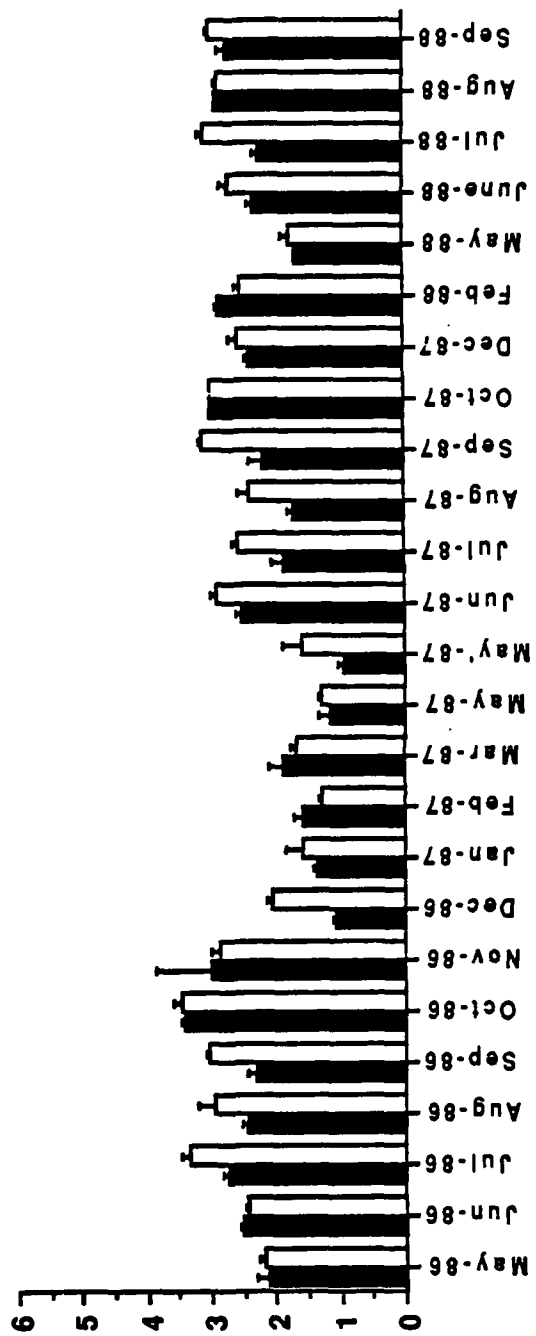


FIGURE 2.9 DIATOM SPECIES DIVERSITY FOR THE FORD RIVER, 1983-88.

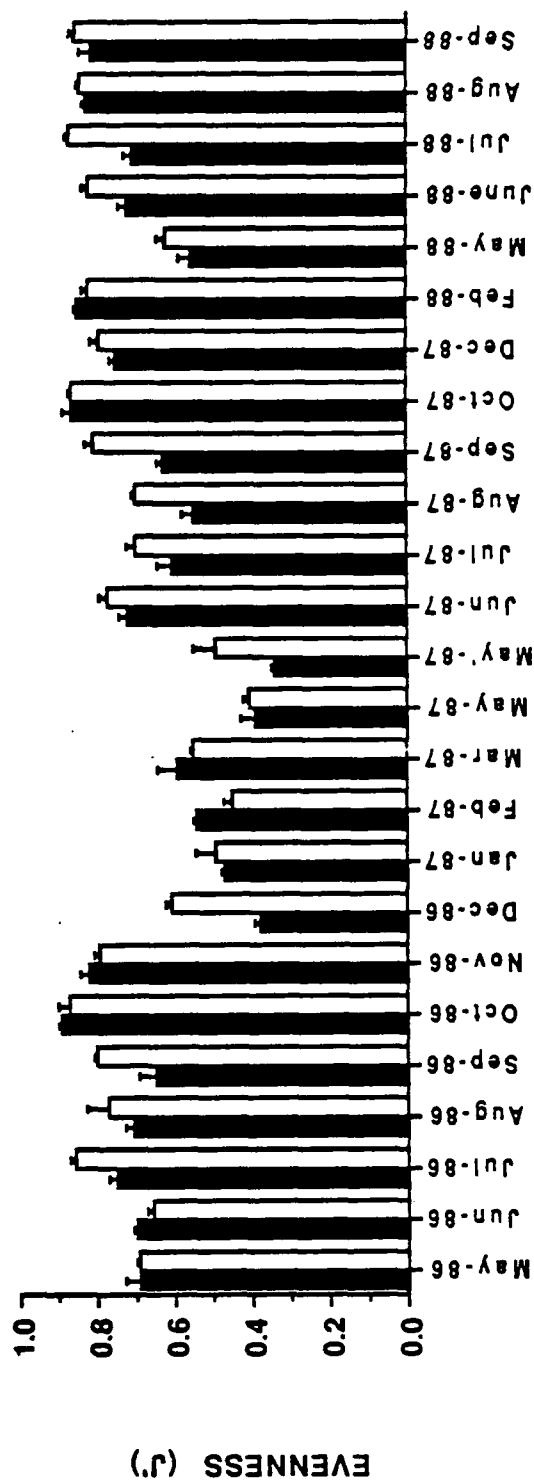
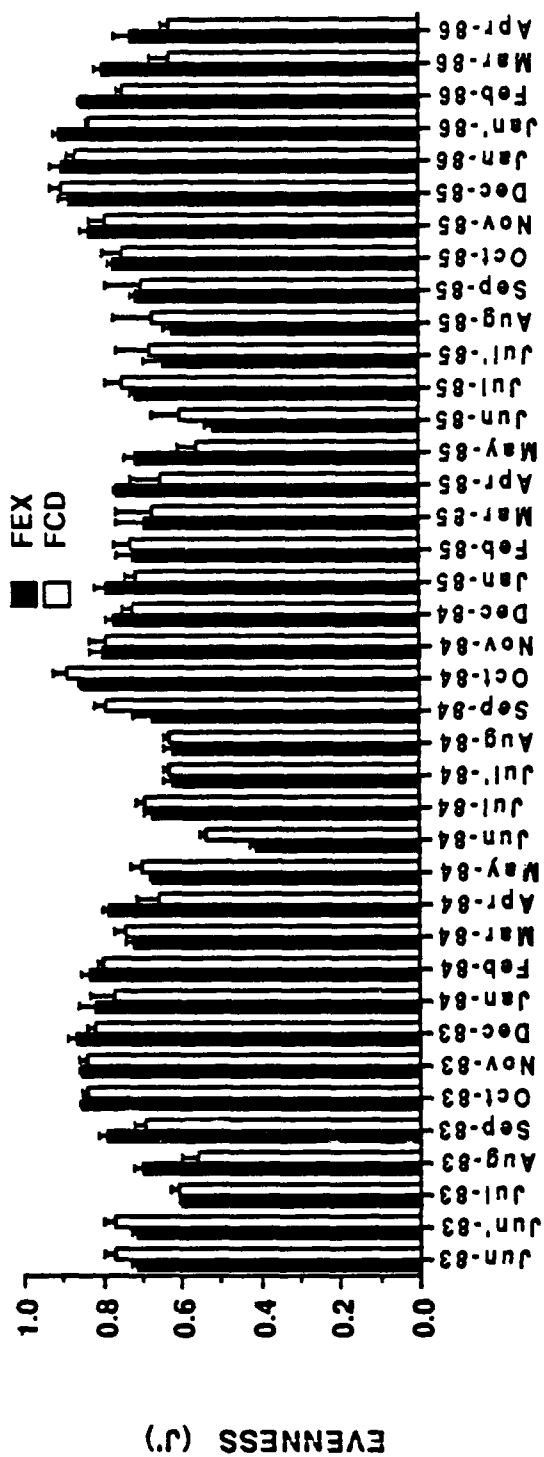
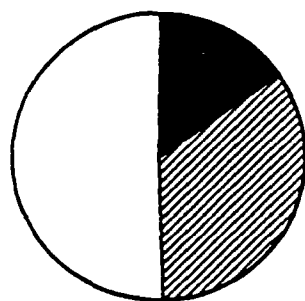


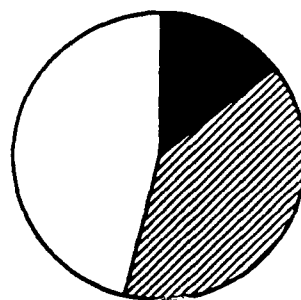
FIGURE 2.10 DIATOM SPECIES EVENNESS FOR THE FORD RIVER, 1983-88.

Table 2.14 Species Diversity (H') and Evenness (J') for Experimental (FEX) and Control (FCD) Sites for 1987-88. Data are Means  $\pm$  S.E., N = 3 except for 12/27 and 2/28 when N = 6.

Date	Experimental (FEX)		Control (FCD)	
	Diversity	Evenness	Diversity	Evenness
10/26/87	2.99 $\pm$ 0.03	0.87 $\pm$ 0.02	2.98 $\pm$ 0.01	0.86 $\pm$ 0.01
12/27/87	2.41 $\pm$ 0.04	0.75 $\pm$ 0.01	2.57 $\pm$ 0.14	0.79 $\pm$ 0.02
2/28/88	2.88 $\pm$ 0.02	0.85 $\pm$ 0.01	2.52 $\pm$ 0.09	0.82 $\pm$ 0.02
5/16/88	1.67 $\pm$ 0.10	0.56 $\pm$ 0.02	1.76 $\pm$ 0.13	0.62 $\pm$ 0.03
6/13/88	2.31 $\pm$ 0.09	0.72 $\pm$ 0.03	2.71 $\pm$ 0.12	0.82 $\pm$ 0.02
7/11/88	2.23 $\pm$ 0.10	0.70 $\pm$ 0.03	3.07 $\pm$ 0.11	0.87 $\pm$ 0.01
8/8/88	2.89 $\pm$ 0.01	0.83 $\pm$ 0.01	2.86 $\pm$ 0.05	0.84 $\pm$ 0.01
9/6/88	2.75 $\pm$ 0.14	0.82 $\pm$ 0.02	3.01 $\pm$ 0.04	0.86 $\pm$ 0.01

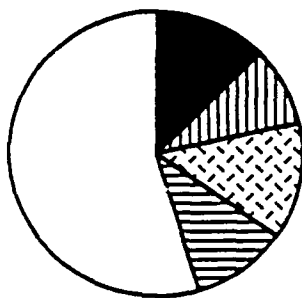


FEX

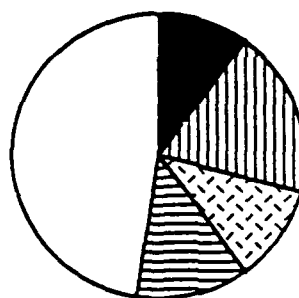


FCD

Summer 1983 (6/83-10/83)



FEX



FCD

Winter 1983 (11/83-4/84)

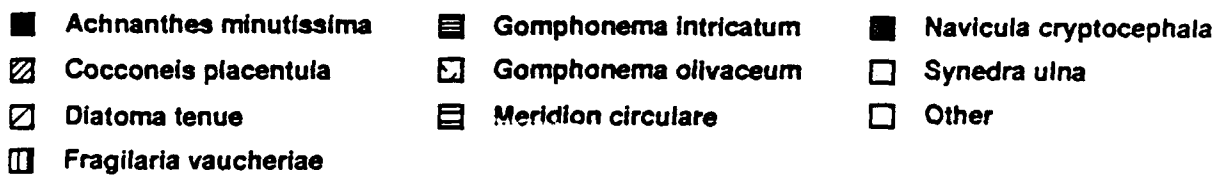
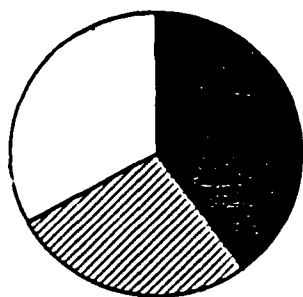
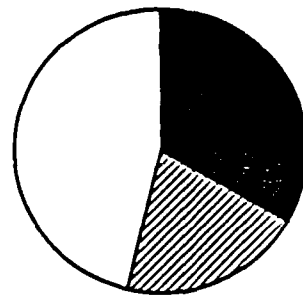


Figure 2.11 Seasonal Diatom Percent Dominance for Experimental (FEX) and Control (FCD) Sites for the Ford River, 1983-88.

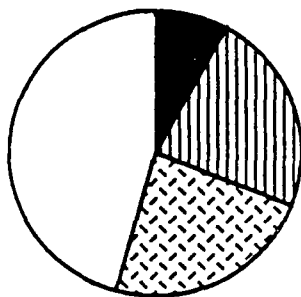


FEX

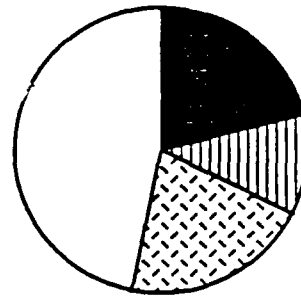


FCD

Summer 1984 (5/84-10/84)

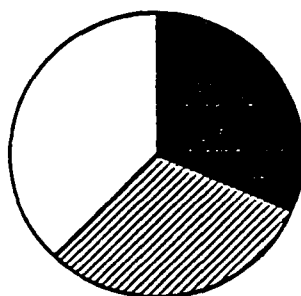


FEX

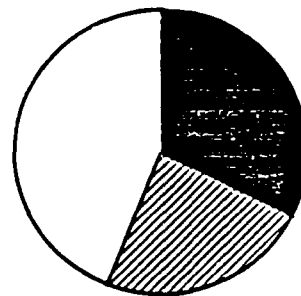


FCD

Winter 1984 (11/84-4/85)



FEX



FCD

Summer 1985 (5/85-10/85)

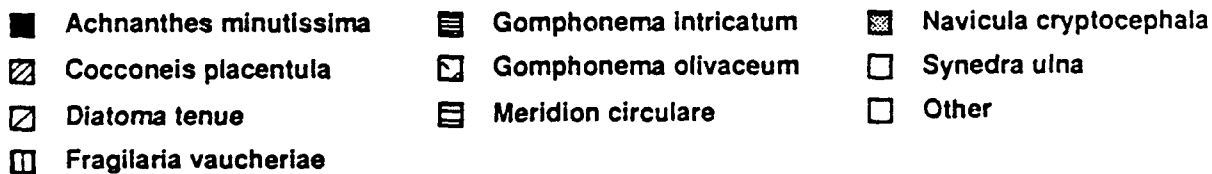
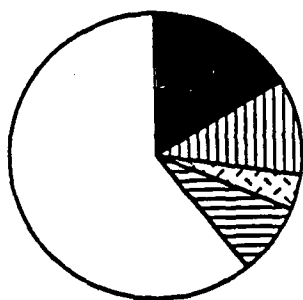
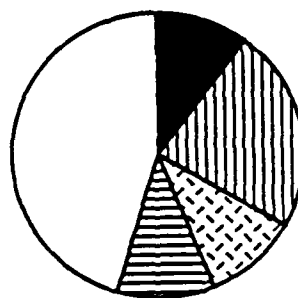


FIGURE 2.11 Seasonal Diatom Percent Dominance, cont.

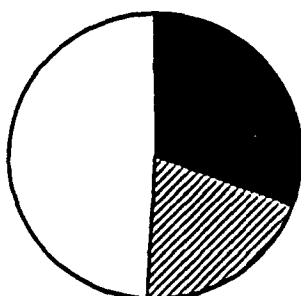


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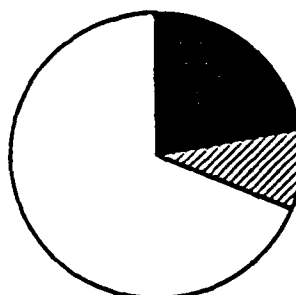


FCD

Winter 1985 (11/85-4/86)

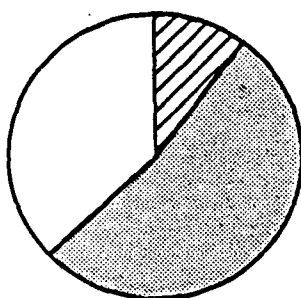


FEX

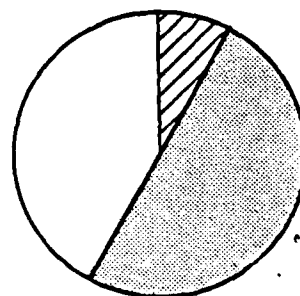


FCD

Summer 1986 (5/86-10/86)



FEX



FCD

Winter 1986 (11/86-4/87)

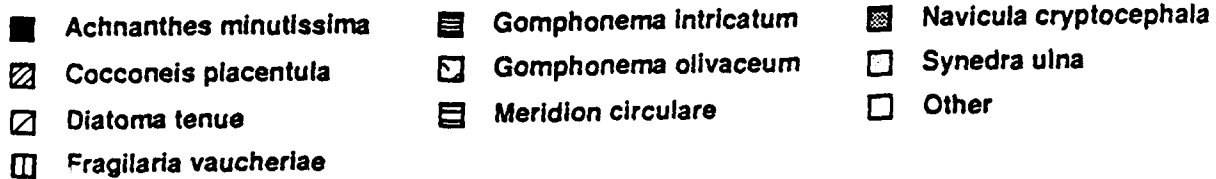
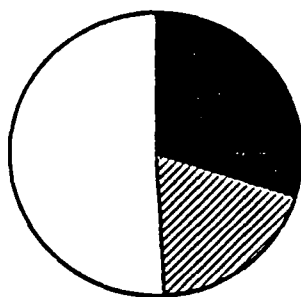
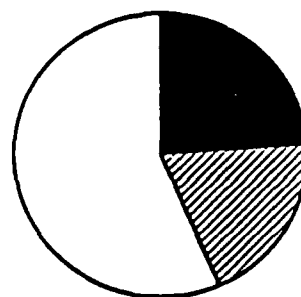


FIGURE 2.11 Seasonal Diatom Percent Dominance, cont.



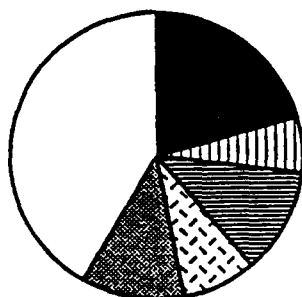


FEX

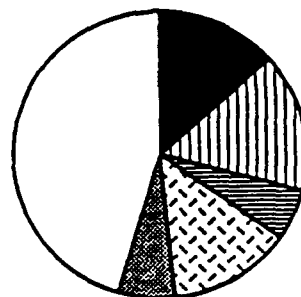


FCD

Summer 1987 (5/87-10/87)

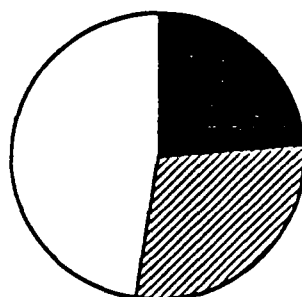


FEX

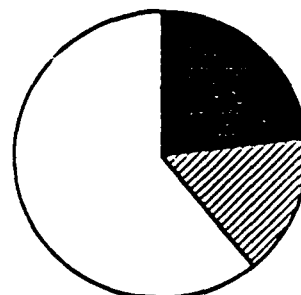


FCD

Winter 1987 (12/87-2/88)



FEX



FCD

Summer 1988 (5/88-9/88)

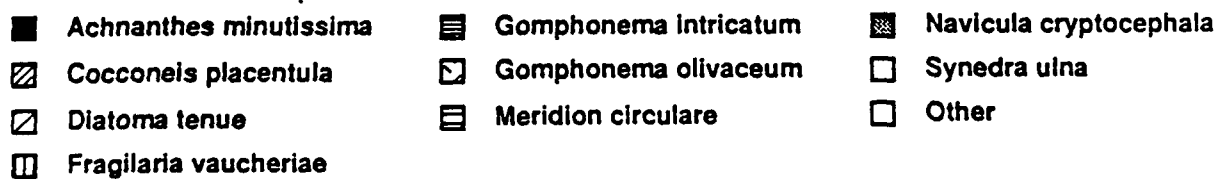


FIGURE 2.11 Seasonal Diatom Percent Dominance, cont.

the five winters monitored to date (Fig. 2.11). In fact, the exceptionally warm winter of 1986 did not follow the normal pattern of dominance by Achnanthes minutissima, Fragilaria vaucheriae, and Gomphonema olivaceum plus one or two other dominant species at all (Fig. 2.11). Instead, the winter of 1986 was dominated by Synedra and Diatoma resulting in the atypical pattern of low diversity and evenness (Figs. 2.9, 2.10).

Non-dominant (< 10%) species such as Achnanthes lanceolata, Cocconeis pediculus, Cymbella minuta, Fragilaria construens and an unidentified Gomphonema species have also responded in a predictable manner throughout the five year period (Figs. 2.12, 2.13, 2.14, 2.15, 2.16). These species can also be divided into species that achieve greatest dominance in winter or summer. Species that are most abundant in summer include only Cocconeis pediculus (Fig. 2.13) and perhaps Cymbella minuta (Fig. 2.14). There are four winter abundant species if one includes Synedra ulna as one of the typical species that does not achieve greater than 10 % dominance (Figs. 2.12, 2.15, 2.16, 2.17). Thus, the combination of greater variability of dominant forms in the winter and more forms that share dominance as well as the preponderance of minor species with peak abundance in the winter leads to the observed pattern in diversity and evenness of winter highs and summer lows (Figs. 2.9, 2.10)

This year we have quantified the changes in diatom abundance over time by analyzing dominant species (> 10%) present in winter and summer with the BACI technique (Table 2.15). Differences between the control and impact sites were calculated using the arcsin + square root of x transformation suggested by Steel and Torrie (1960) for percentage data. There were no significant differences in FEX and FCD before and after testing of the ELF antenna began in the summer of 1986 for any of the five summer or winter species when the entire 83-85 "before" data were compared to the 86-88 "after" data (Table 2.15). In fact, no comparison of summer data for either of the two dominant summer species showed any significant difference between any of the before years of 1983, 84, 85 and any of the years after testing began in 1986 (1986, 87, 88). Regressions run on the winter species indicated that some "before" and "after" data were not additive (Table 2.15). The small number of available data points for several years probably increased the chance for finding significant regressions. Significant differences between means were produced for several year-to-year comparisons. These significant differences were produced for comparisons within the "before" period, and were the result of a limited number

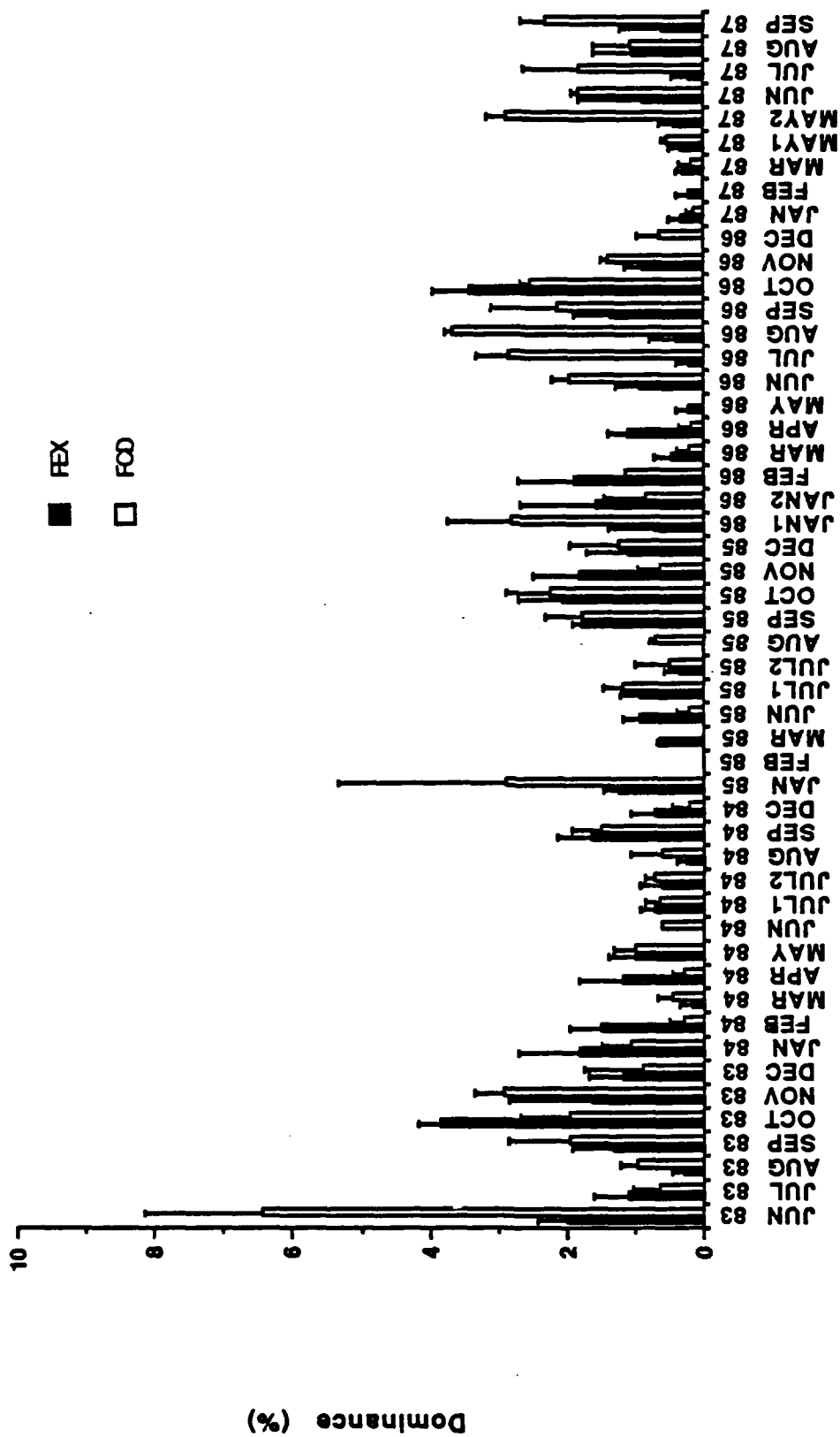


Figure 2.12 *Achnanthes lanceolata* PERCENT DOMINANCE FOR THE FORD RIVER, 1983-87.

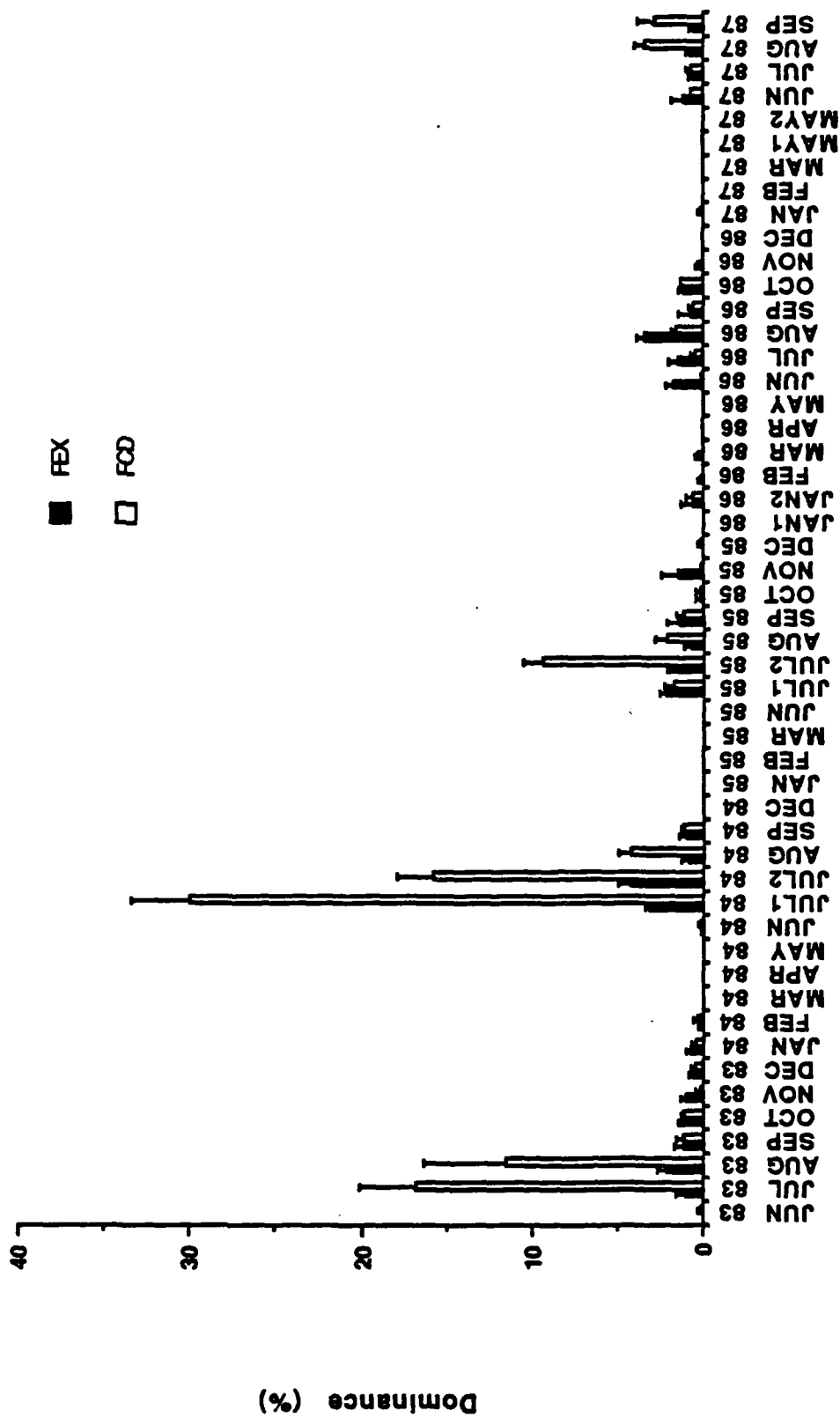


Figure 2.13 Cocconel pediculus PERCENT DOMINANCE FOR THE FORD RIVER, 1983-87.

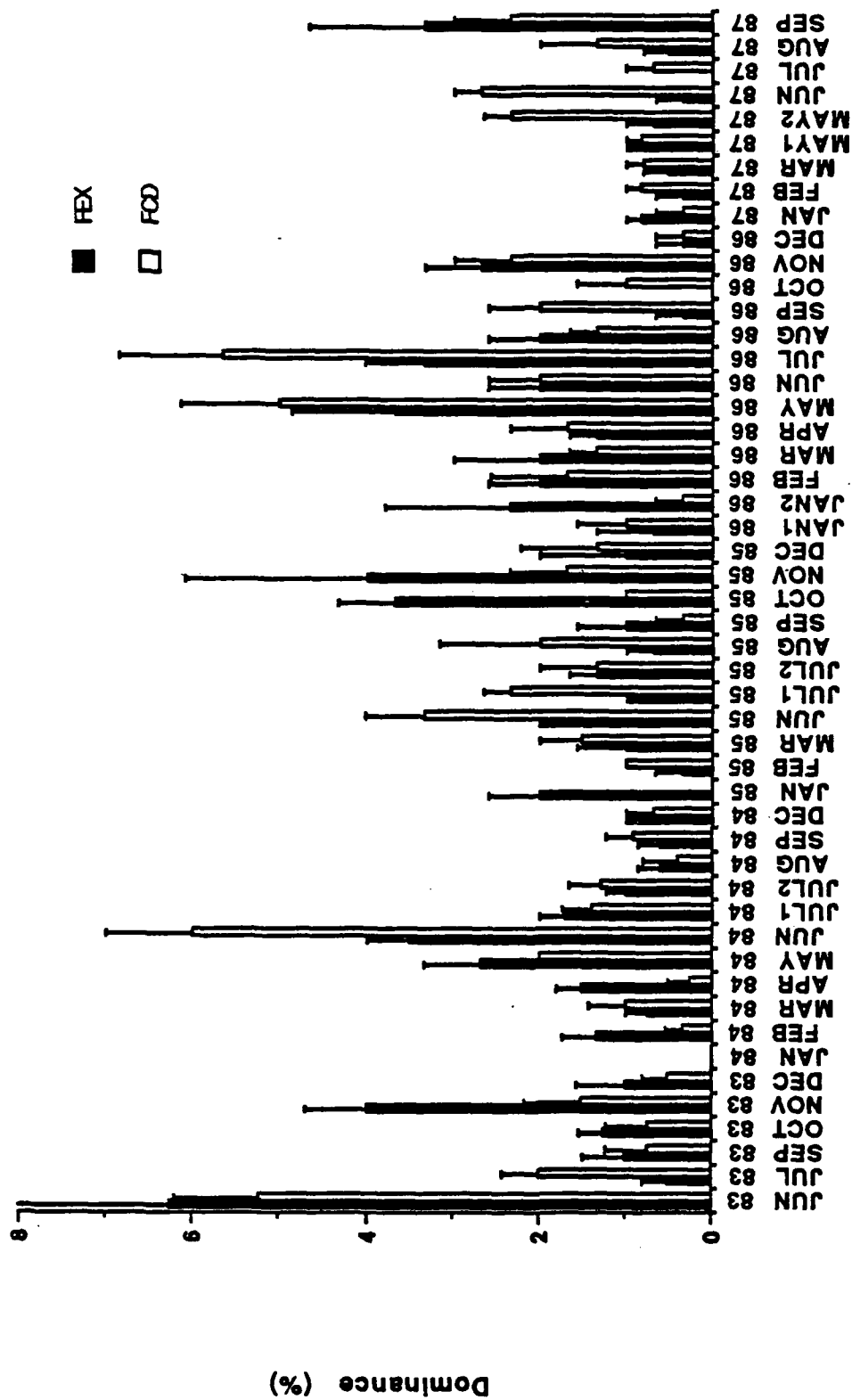


Figure 2.14 *Cymbella minuta* PERCENT DOMINANCE FOR THE FORD RIVER, 1983-87.

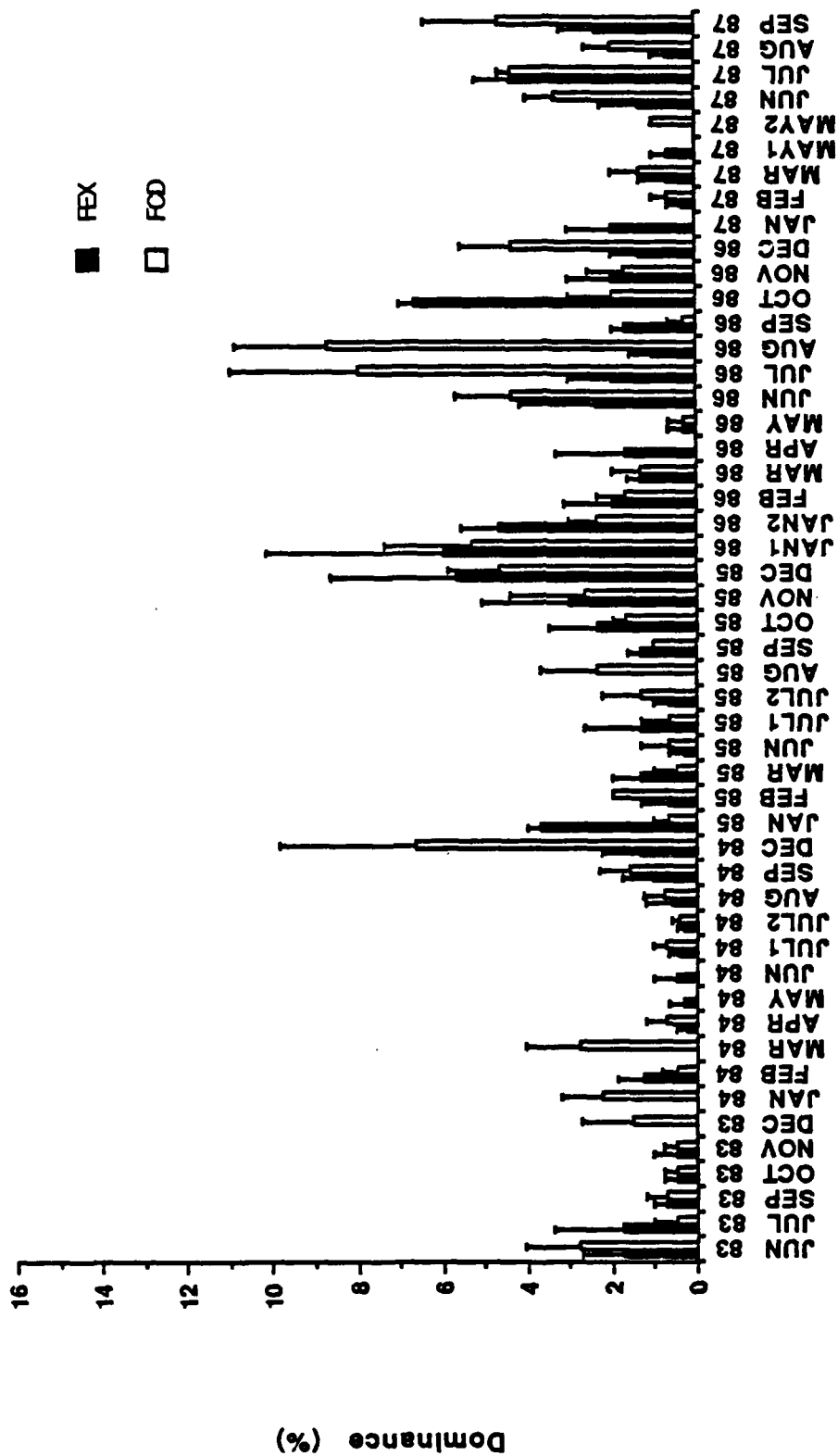


Figure 2.15 *Fragillaria construens* PERCENT DOMINANCE FOR THE FORD RIVER, 1983-87.

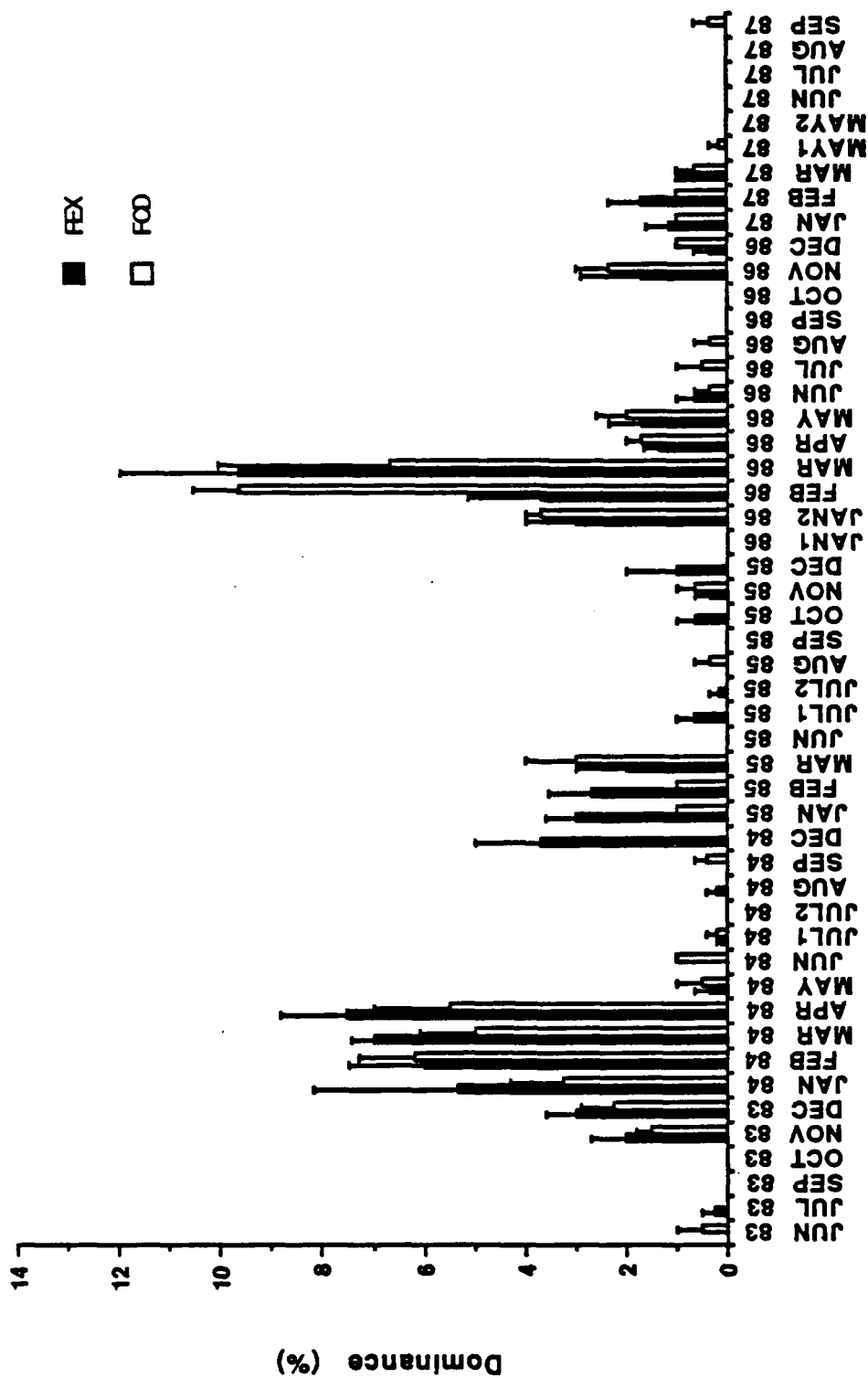


Figure 2. 16 Gomphonema sp. PERCENT DOMINANCE FOR THE  
FORD RIVER, 1983-87.

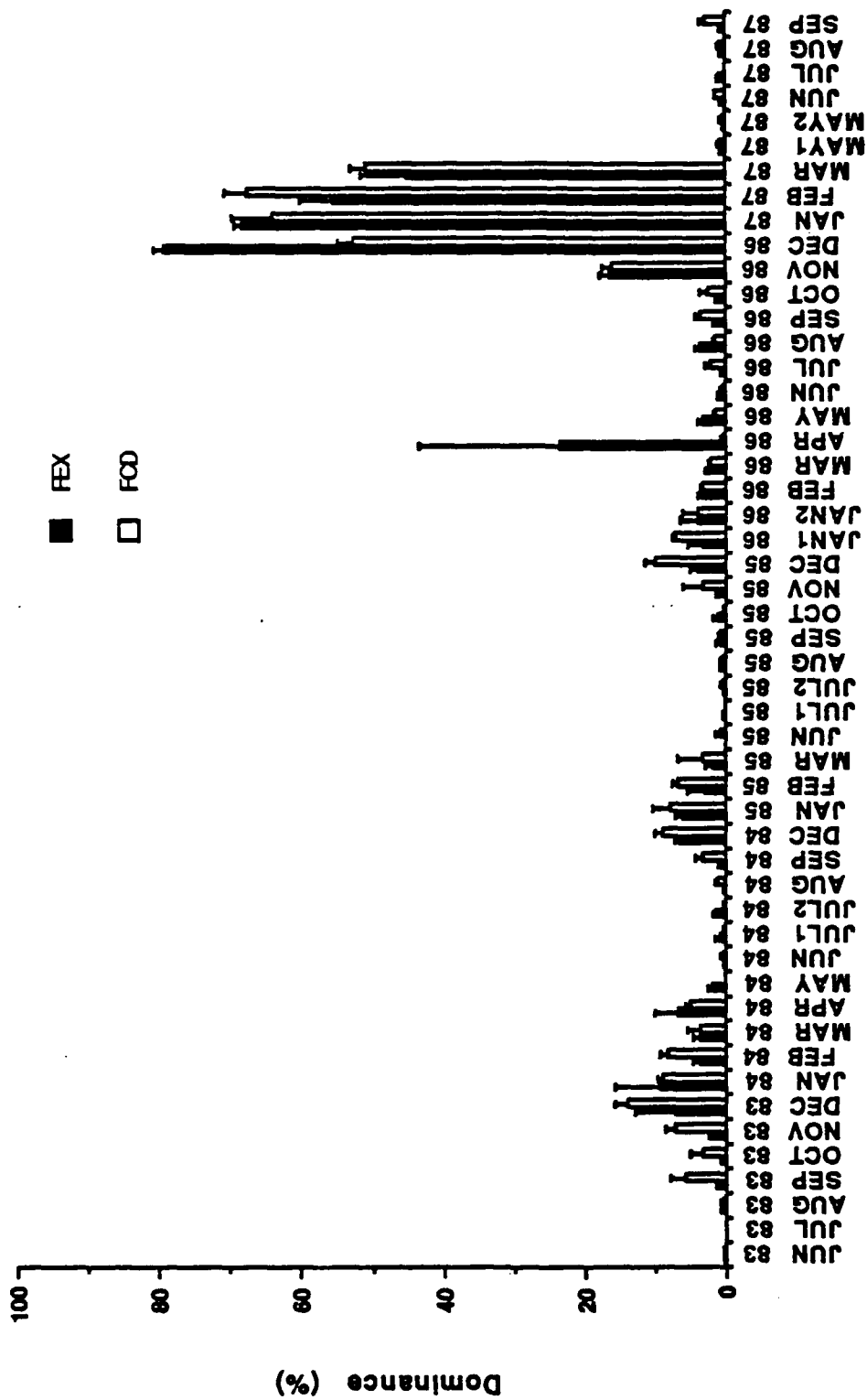


Figure 2. 17 *Synedra ulna* PERCENT DOMINANCE FOR THE FORD RIVER, 1983-87.



Table 2.15 Results of BACI Comparisons of Dominant Diatoms between Control (FCD) and Experimental (FEX) Sites, 1983-88.

Species	Comparison	DF	Tukey's Test for Additivity			Sig. p < 0.05	t - test		
			BEFORE Prob.	DF	AFTER Prob.		Unpaired t-value	Probability (two-tailed)	Sig. p < 0.05
<i>Achnanthes minutissima</i>	S 83-85/88-88	13	0.064	16	0.335	NS	-0.829	0.414	NS
	S 83/84	1	-	5	0.383	NS	-0.658	0.535	NS
	S 83/85	1	-	5	0.106	NS	0.348	0.740	NS
	S 83/86	1	-	5	0.598	NS	-0.862	0.422	NS
	S 83/87	1	-	5	0.354	NS	-0.386	0.713	NS
	S 83/88	1	-	4	0.606	NS	0.079	0.940	NS
	S 84/85	5	0.383	5	0.106	NS	1.349	0.207	NS
	S 84/86	5	0.383	5	0.598	NS	-0.528	0.609	NS
	S 84/87	5	0.383	5	0.354	NS	0.034	0.974	NS
	S 84/88	5	0.383	4	0.606	NS	0.986	0.350	NS
	S 85/86	5	0.106	5	0.598	NS	-1.685	0.123	NS
	S 85/87	5	0.106	5	0.354	NS	-0.934	0.372	NS
	S 85/88	5	0.106	4	0.606	NS	-0.358	0.728	NS
	S 86/87	5	0.598	5	0.354	NS	0.448	0.664	NS
	S 86/88	5	0.598	4	0.606	NS	1.335	0.215	NS
	S 87/88	5	0.354	4	0.606	NS	0.649	0.533	NS
<i>Cocconeis placentula</i>	S 83-85/88-88	13	0.515	16	0.255	NS	-1.058	0.299	NS
	S 83/84	1	-	5	0.629	NS	-2.620	0.040	S
	S 83/85	1	-	5	0.410	NS	-2.322	0.059	NS
	S 83/86	1	-	5	0.836	NS	-2.374	0.055	NS
	S 83/87	1	-	5	0.710	NS	-1.060	0.330	NS
	S 83/88	1	-	4	0.285	NS	-1.519	0.189	NS
	S 84/85	5	0.629	5	0.410	NS	0.197	0.848	NS
	S 84/86	5	0.629	5	0.836	NS	-0.989	0.346	NS
	S 84/87	5	0.629	5	0.710	NS	1.162	0.272	NS
	S 84/88	5	0.629	4	0.285	NS	-1.026	0.332	NS
	S 85/86	5	0.410	5	0.836	NS	-1.089	0.302	NS
	S 85/87	5	0.410	5	0.710	NS	0.994	0.344	NS

Table 2.15 Results of BACI Comparisons of Dominant Diatoms, continued.

Species	Comparison	Tukey's Test for Additivity				t-test		
		BEFORE	Sig.	AFTER	Sig.	Unpaired	Probability	Sig.
		Prob.	p < 0.05	Prob.	p < 0.05	t-value	(two-tailed)	p < 0.05
Coconeis placentula	S 85/88	0.410	NS	0.285	NS	-1.087	0.305	NS
	S 86/87	0.836	NS	0.710	NS	1.717	0.117	NS
	S 86/88	0.836	NS	0.285	NS	-0.469	0.650	NS
	S 87/88	0.710	NS	0.285	NS	-1.518	0.163	NS
Achnanthes minutissimala	W 83-85/86-87	0.084	NS	0.360	NS	-0.052	0.959	NS
	W 83/84	0.199	NS	0.031	S	3.217	0.012	S
	W 83/85	0.199	NS	0.013	S	-2.254	0.046	NS
	W 83/86	0.199	NS	0.370	NS	1.339	0.210	NS
	W 83/87	0.199	NS	-	-	-1.768	0.127	NS
	W 84/85	0.031	S	0.013	S	-4.318	0.002	S
	W 84/86	0.031	S	0.370	NS	-2.273	0.053	NS
	W 84/87	0.031	S	-	-	-2.318	0.081	NS
	W 85/86	0.013	S	0.370	NS	3.067	0.011	S
	W 85/87	0.013	S	-	-	0.065	0.950	NS
	W 86/87	0.370	NS	-	-	-1.945	0.100	NS
	W 83-85/86-87	0.668	NS	0.001	S	1.557	0.133	NS
	W 83/84	0.044	S	0.299	NS	-2.437	0.041	S
	W 83/85	0.044	S	0.897	NS	0.474	0.645	NS
Fragilaria vaucheriae	W 83/86	0.044	S	0.001	S	0.898	0.391	NS
	W 83/87	0.044	S	-	-	-0.053	0.960	NS
	W 84/85	0.299	NS	0.697	NS	0.924	0.380	NS
	W 84/86	0.299	NS	0.001	S	1.684	0.131	NS
	W 84/87	0.299	NS	-	-	1.511	0.2053	NS
	W 85/86	0.697	NS	0.001	S	0.822	0.428	NS
	W 85/87	0.697	NS	-	-	-0.421	0.687	NS
	W 86/87	0.001	S	-	-	-0.519	0.622	NS
	W 83-85/86-87	0.668	NS	0.001	S	1.557	0.133	NS
	W 83/84	0.044	S	0.299	NS	-2.437	0.041	S

Table 2.15 Results of BACI Comparisons of Dominant Diatoms, continued.

Species	Comparison	Tukey's Test for Additivity				t-test		
		BEFORE	DF	Prob.	Sig.	Unpaired	Probability	Sig.
					p < 0.05	t-value	(two-tailed)	p < 0.05
Gomphonema	W 83-85/86-87	0.313	18	0.431	NS	0.556	0.584	NS
olivaceum	W 83/84	0.988	5	0.693	NS	0.178	0.863	NS
	W 83/85	0.988	5	0.108	NS	2.580	0.026	S
	W 83/86	0.988	5	0.841	NS	1.546	0.153	NS
	W 83/87	0.988	5	-	-	1.213	0.271	NS
	W 84/85	0.893	3	0.108	NS	2.661	0.026	S
	W 84/86	0.893	3	0.841	NS	2.088	0.073	NS
	W 84/87	0.693	3	-	-	1.481	0.213	NS
	W 85/86	0.108	6	0.841	NS	-1.824	0.095	NS
	W 85/87	0.108	6	-	-	-0.418	0.688	NS
	W 86/87	0.841	5	-	-	0.847	0.429	NS

of available data points. It is apparent that the use of species abundance data for individual diatom species coupled with the BACI analysis of this diatom percent dominance data provides a potentially powerful tool for determining the impact of ELF exposure. In future years, we will expand these analyses to include the non-dominant species that exhibit relatively constant year to year patterns of abundance (Figs. 2.12 - 2.17).

Comparisons of diversity and evenness (Figs. 2.9, 2.10) between sites through paired t-tests indicated no significant differences in diversity or evenness between sites for 1987-88 (Table 2.2) or for all data collected through 1988 (Table 2.3). Correlation coefficients of 0.68 for diversity and 0.79 for evenness indicated the close relationship of these parameters between the two sites for 1987-88 (Table 2.2). Even so, these relationships were not as highly correlated as they were when all data were considered (Table 2.3). The close relationship expected between evenness and diversity was evident from the significant ( $p < 0.01$ ) correlation coefficients at each site ( $r = 0.711$  at FEX and  $0.666$  at FCD).

Results of BACI comparisons for diversity and evenness demonstrated significant differences in means for the lumped "before" (6/83-4/86) and "after" (5/86-9/88) data (Tables 2.16, 2.17). Seasonal lumped comparisons of mean differences in diversity were not significant (Table 2.16), and, in fact, the only year to year comparison that was significantly different was the comparison of the summer of 83 to the summer of 87. Year to year comparisons of evenness resulted not only in the difference between the summer of 83 and 87 that had been true for diversity but also in a significant difference between the summer of 85 and 87 (Table 2.17). Evenness differed from diversity also in the fact that the overall comparison (83-85 vs. 86-88) was different for both summer and winter data (Tables 2.16, 2.17). The fact that most year to year comparisons do not support the overall conclusion and that there were no differences in the summer 1988 data (the year of maximum ELF exposure to date) and any other year suggest that ELF effects may not be the primary cause of the year to year differences in evenness and diversity for 1987 or for diversity and evenness overall.

The only chemical parameter that was significantly ( $p < 0.05$ ) correlated with diversity was silicate-Si ( $r = 0.31$  at FEX and  $0.36$  at FCD). Evenness was also significantly

Table 2.16 Results of BACI Comparisons of Diversity between Control (FCD) and Experimental (FEX) Sites, 1983-88.

Comparison: (Bet/Aft, Bet/Bet, or Aft/Aft)	Tukey's Test for Additivity*				t-test				
	BEFORE Prob.	Sig. p < 0.05	DF	AFTER Prob.	Sig. p < 0.05	DF	Unpaired t-value	Probability (two-tailed)	Sig. p < 0.05
6/83-4/86 // 5/86-9/88	0.835	NS	24	0.892	NS	62	2.624	0.011	S
S 83-85/86-88	0.896	NS	16	0.485	NS	35	1.964	0.058	NS
S 83/84	0.984	NS	6	0.917	NS	11	1.686	0.120	NS
S 83/85	0.984	NS	6	0.957	NS	11	0.575	0.577	NS
S 83/86	0.984	NS	5	0.753	NS	10	1.624	0.136	NS
S 83/87	0.984	NS	5	0.396	NS	10	2.762	0.020	S
S 83/88	0.984	NS	4	0.802	NS	9	1.542	0.157	NS
S 84/85	0.917	NS	6	0.957	NS	12	-0.997	0.338	NS
S 84/86	0.917	NS	5	0.753	NS	11	-0.122	0.905	NS
S 84/87	0.917	NS	5	0.396	NS	11	1.050	0.316	NS
S 84/88	0.917	NS	4	0.802	NS	10	-0.125	0.903	NS
S 85/86	0.957	NS	5	0.753	NS	11	0.894	0.390	NS
S 85/87	0.957	NS	5	0.396	NS	11	1.927	0.080	NS
S 85/88	0.957	NS	4	0.802	NS	10	0.835	0.423	NS
S 86/87	0.753	NS	5	0.396	NS	10	1.259	0.237	NS
S 86/88	0.753	NS	4	0.802	NS	9	-0.009	0.993	NS
S 87/88	0.396	NS	4	0.802	NS	9	-1.238	0.247	NS
W 83-85/86-87	0.961	NS	7	0.382	NS	25	1.208	0.238	NS
W 83/84	0.528	NS	5	0.742	NS	10	-0.046	0.964	NS
W 83/85	0.528	NS	6	0.132	NS	11	0.193	0.850	NS
W 83/86	0.528	NS	5	0.599	NS	10	1.270	0.233	NS
W 83/87	0.528	NS	1	-	-	6	0.360	0.731	NS
W 84/85	0.742	NS	6	0.132	NS	11	0.194	0.850	NS
W 84/86	0.742	NS	5	0.599	NS	10	0.975	0.352	NS
W 84/87	0.742	NS	1	-	-	6	0.242	0.817	NS
W 85/86	0.132	NS	5	0.599	NS	11	0.945	0.365	NS
W 85/87	0.132	NS	1	-	-	7	0.150	0.885	NS
W 86/87	0.599	NS	1	-	-	6	-0.546	0.604	NS

\*Data was not transformed

Table 2.17 Results of BACI Comparisons of Evenness between Control (FCD) and Experimental (FEX) Sites, 1983-88.

Comparison: (Bel/Ait, Bel/Bef, or Ait/Ait)	DF	Tukey's Test for Additivity*			Sig. p < 0.05	DF	AFTER Prob.	Sig. p < 0.05	t-test*	
		BEFORE Prob.	Sig. p < 0.05	DF					Unpaired t-value	Probability (two-tailed)
6/83-4/86 //	38	0.163	NS	24	0.401	62	3.726	0.0004	S	
5/86-9/88										
S 83-85/86-88	19	0.497	NS	16	0.061	35	2.487	0.018	S	
S 83/84	5	0.563	NS	6	0.371	11	1.904	0.083	NS	
S 83/85	5	0.563	NS	6	0.711	11	0.565	0.584	NS	
S 83/86	5	0.563	NS	5	0.935	10	1.372	0.200	NS	
S 83/87	5	0.563	NS	5	0.092	10	2.829	0.018	S	
S 83/88	5	0.563	NS	4	0.865	9	2.147	0.060	NS	
S 84/85	6	0.371	NS	6	0.711	12	-1.323	0.211	NS	
S 84/86	6	0.371	NS	5	0.935	11	-0.324	0.752	NS	
S 84/87	6	0.371	NS	5	0.092	11	1.525	0.155	NS	
S 84/88	6	0.371	NS	4	0.865	10	0.625	0.546	NS	
S 85/86	6	0.711	NS	5	0.935	11	0.863	0.406	NS	
S 85/87	6	0.711	NS	5	0.092	11	2.418	0.034	S	
S 85/88	6	0.711	NS	4	0.865	10	1.661	0.128	NS	
S 86/87	5	0.935	NS	5	0.092	10	1.564	0.149	NS	
S 86/88	5	0.935	NS	4	0.865	9	0.799	0.445	NS	
S 87/88	5	0.092	NS	4	0.865	9	-0.853	0.416	NS	
W 83-85/86-87	18	0.098	NS	7	0.591	25	2.317	0.029	S	
W 83/84	5	0.590	NS	5	0.719	10	-0.165	0.872	NS	
W 83/85	5	0.590	NS	6	0.036	11	-1.013	0.333	NS	
W 83/86	5	0.590	NS	5	0.639	10	1.106	0.295	NS	
W 83/87	5	0.590	NS	1	-	6	1.230	0.265	NS	
W 84/85	5	0.719	NS	6	0.036	11	-0.880	0.398	NS	
W 84/86	5	0.719	NS	5	0.639	10	1.191	0.261	NS	
W 84/87	5	0.719	NS	1	-	6	1.385	0.215	NS	
W 85/86	6	0.036	S	5	0.639	11	1.712	0.115	NS	
W 85/87	6	0.036	S	1	-	7	1.652	0.142	NS	
W 86/87	5	0.639	NS	1	-	6	-0.141	0.893	NS	

\*Data was log(x+1) transformed

correlated with Si at FCD ( $r=0.30$ ) but not at FEX. No physical parameter was correlated with either diversity or evenness. In addition to the correlation of diversity with evenness already mentioned, diversity was significantly ( $p<.05$ ), negatively correlated with biovolume ( $r=-0.52$  for FEX and  $-0.51$  for FCD), cell volume ( $r=-0.35$  for both sites), density ( $r=-0.51$  for FEX and  $-0.38$  for FCD), and chlorophyll *a* ( $r=-0.38$  for FEX and  $-0.31$  for FCD). The same type of correlations held for evenness also except that it was not significantly correlated with chlorophyll *a*.

#### H. Effects of Environmental Variables on the Periphyton Community

The entire set of data on physical, chemical, and biological parameters collected since 1983 was separated by site and entered for calculation of correlation coefficients. These relationships have been discussed above as appropriate. Other approaches have been used in the past and will be included in future reports. A brief synopsis of some of these approaches is included here.

The multiple regressions calculated for the June 1983 to June 1985 data sets for each site were presented in the annual reports for 1984-85 and for 1985-86 and were not repeated for 1986-87 or 1987-88. Likewise, variable transformations were performed in 1985-86 to determine the linearity of variable relationships. These will not be repeated for this report but may be useful when the factor analyses are more thoroughly investigated. Our conclusion from the 1985-86 report that "an overall correlation matrix appeared to be as robust using untransformed data as any transformation attempted" was one reason for the determination of correlation coefficients on our entire data set for 1983 through 1988.

Stepwise regressions in 1986 for chlorophyll *a* and the ambient monitoring parameters indicated that water temperature alone explained 61% of the variance followed by conductivity of the water (33%). Water temperature was the only significantly important factor for organic matter standing crop and accounted for only 36% of the variability. Between the biological variables, organic matter biomass explained 55% of the variance in diatom cell density. Only water temperature of the physical and chemical variables was even weakly correlated with density.

Thus, we have tried correlation matrices on transformed and untransformed data in the past and have also tried

multiple and stepwise regressions. The correlation matrix on untransformed data seems to yield as much information as any of the other approaches. Nevertheless, we do plan to subject the data to multiple regression and stepwise regression analyses at the end of the study. We may also try principal components analyses in the future and illustrate this technique on the grazer data that follows in Element 3.

### I. Photosynthesis-Respiration Studies

A separate study was undertaken to evaluate primary production and community respiration using short term changes in dissolved oxygen concentrations during the summer period of intense algal growth. The dissolved gas procedures are advantageous because estimates of net primary production, gross primary production, and community respiration may be obtained with one technique (Bott *et al.* 1979). Rocks from the stream bed were placed inside each of six plexiglass chambers occupying 1/3 to 1/4 of the total chamber volume of 3-4 L. Three light and three dark chambers were run simultaneously on each date. Recirculated water was continuously recycled through the chambers using submersible pumps. Each test lasted from 0.5-2.0 hours between 1000 and 1300 hours of each test day in 1984. One site was tested during one week, and the second was tested during the following week in 1984. Even though 1984 results indicated no significant difference (t-test) between sites for net production, respiration, or gross production, the relatively large standard deviations led us to change procedures concerning exposure durations and site selection for 1985. Since 1985, production and respiration studies at FCD and FEX have been conducted on the same day with the test at each site lasting one hour. Tests were begun at one site at 1000 hours and completed at the other site by 1400 hours. Each site was tested first on alternate weeks.

The assumptions made for the purposes of production calculations considered algal periphyton to occupy only the upper surface half of each rock. Chlorophyll *a*, extracted from rocks covered by attached periphyton, was measured for each chamber with a fluorimeter. Surface area was determined by wrapping each rock in aluminum foil, straightening the foil, and determining the area of foil using a leaf area meter (LI-COR). Hourly production and respiration rates were estimated (Table 2.18) from dissolved oxygen, chlorophyll *a*, and rock surface area measurements.

We agree with reviewers from past years that production and respiration studies should be done for as many seasons of



Table 2.18 Hourly Production and Respiration Rates for Rock Substrates of the Ford River.

Date	NET PRIMARY PRODUCTION			RESPIRATION*			GROSS PRIMARY PRODUCTION**		
	mgO <sub>2</sub> /m <sup>2</sup>	mg Chl a/m <sup>2</sup>	mgO <sub>2</sub> /mg Chl a	mgO <sub>2</sub> /m <sup>2</sup>	mg Chl a/m <sup>2</sup>	mgO <sub>2</sub> /mg Chl a	mgO <sub>2</sub> /m <sup>2</sup>	mgO <sub>2</sub> /mg Chl a	mg Chl a
FORD CONTROL SITE (FCD)									
6/23/88	87.32 ± 28.84	33.17 ± 11.73	2.75 ± 1.11	53.29 ± 21.82	25.94 ± 12.57	2.82 ± 2.42	140.61		5.57
7/5/88	92.14 ± 6.18	24.65 ± 0.00	3.74 ± 0.25	46.86 ± 7.70	24.78 ± 3.06	1.82 ± 0.28	139.00		5.56
7/7/88	60.23 ± 9.81	16.75 ± 6.74	3.75 ± 0.81	48.13 ± 13.34	17.37 ± 7.28	3.25 ± 2.08	108.36		7.00
7/12/88	36.55 ± 8.68	17.59 ± 2.42	2.03 ± 0.43	36.93 ± 14.26	27.65 ± 7.77	1.32 ± 0.32	73.48		3.35
7/14/88	79.56 ± 22.03	29.00 ± 17.98	3.36 ± 1.51	12.91 ± 7.27	16.42 ± 8.59	0.99 ± 0.64	92.47		4.35
7/19/88	91.15 ± 24.22	25.27 ± 11.91	3.92 ± 1.05	49.61 ± 38.32	16.58 ± 9.70	2.87 ± 0.68	140.76		6.79
7/26/88	58.16 ± 22.92	20.74 ± 6.70	2.70 ± 0.32	18.51 ± 2.78	23.55 ± 1.39	0.79 ± 0.13	76.67		3.49
8/9/88	66.16 ± 0.41	25.63 ± 7.42	2.76 ± 0.95	21.31 ± 2.13	31.44 ± 0.80	0.68 ± 0.08	87.47		3.44
8/23/88	101.80 ± 20.71	31.66 ± 2.25	3.25 ± 0.82	22.44 ± 5.65	22.83 ± 6.25	1.00 ± 0.21	124.24		4.25
8/30/88	58.48 ± 9.69	23.57 ± 10.39	2.85 ± 1.67	31.12 ± 12.33	33.33 ± 11.06	0.97 ± 0.33	89.60		3.82
Ave ± S.D.	73.15 ± 20.39	24.80 ± 5.48	3.11 ± 0.60	34.11 ± 14.82	23.99 ± 5.95	1.65 ± 0.98	107.27 ± 26.94		6.76 ± 1.38
FORD EXPERIMENTAL SITE (FEX)									
6/23/88	120.57 ± 28.36	28.87 ± 4.88	4.27 ± 1.35	21.87 ± 5.73	29.23 ± 3.22	0.76 ± 0.25	142.44		5.03
7/5/88	83.30 ± 48.77	23.77 ± 8.37	3.28 ± 1.36	34.01 ± 8.44	25.57 ± 6.30	1.40 ± 0.52	117.31		4.68
7/7/88	95.15 ± 38.63	18.33 ± 6.25	5.14 ± 0.96	70.40 ± 16.45	20.09 ± 2.81	3.50 ± 0.53	165.55		8.64
7/12/88	76.03 ± 8.75	23.56 ± 6.75	3.47 ± 1.17	22.75 ± 15.56	33.19 ± 1.28	0.68 ± 0.45	99.38		4.15
7/14/88	97.18 ± 41.63	19.81 ± 4.12	5.23 ± 2.96	28.10 ± 13.95	22.92 ± 3.59	1.19 ± 0.45	125.28		6.42
7/19/88	117.64 ± 20.77	25.27 ± 4.16	4.83 ± 1.63	39.68 ± 6.84	31.69 ± 14.11	1.43 ± 0.71	157.32		6.26
7/26/88	97.19 ± 43.70	39.55 ± 10.63	2.45 ± 0.93	47.41 ± 13.24	25.09 ± 5.50	1.88 ± 0.21	144.90		4.33
8/9/88	146.85 ± 46.76	39.53 ± 10.03	3.77 ± 1.02	72.47 ± 18.32	36.39 ± 3.18	1.99 ± 0.46	219.32		5.76
8/23/88	149.33 ± 23.71	49.56 ± 10.53	3.16 ± 1.03	60.04 ± 9.60	51.33 ± 11.99	1.25 ± 0.55	209.37		4.41
8/30/88	83.81 ± 11.60	30.80 ± 4.46	2.76 ± 0.52	24.01 ± 9.14	38.59 ± 7.04	0.61 ± 0.11	107.82		3.37
Ave ± S.D.	106.77 ± 25.89	29.91 ± 10.05	3.84 ± 0.99	42.10 ± 19.59	31.41 ± 9.16	1.47 ± 0.85	148.90 ± 40.42		5.31 ± 1.52

\* = Gross Respiration of Entire Microbial Community (Bacteria and Algae)

\*\* = Total Metabolism = Respiration + Net Primary Production

the year as possible. However, these procedures are labor intensive (ca. 40-50 hours per determination or 400 to 500 hours for the 10 runs per summer) and can only be done with present level of funding during times when student technicians are available (June 15 through September 1). Thus, these determinations will be done in this period only unless additional funds are forthcoming for studies during other seasons. We also agree that  $^{14}\text{C}$  studies would be a better way to go than just monitoring changes in dissolved oxygen. Again, lack of equipment and funding to purchase such equipment precludes this as well.

Gross and net primary production and respiration were very similar between the control (FCD) and experimental (FEX) sites for 1988 (Table 2.18). The modified procedures used in 1985-86-87-88 have resulted in lower standard deviations for each parameter and in additional convergence of mean values between sites compared to 1984. Up to this point we have not included any statistical analysis of the production and respiration studies. However, it may be possible to analyze net primary production rates with the BACI technique, since it appears that this community based comparison offers a robust means for detection of potential ELF effects. We will certainly compare results between sites using paired t tests for each year for the final report.

## J. Summary

### 1. Chlorophyll a

Annual patterns for chlorophyll a standing crop and accrual were characterized by large year to year variability. The only consistent trend was for July-August peaks in most years and winter lows. The magnitudes of peaks also varied between years. Paired t-tests for 1987-88 data showed no differences between our control (FCD) and experimental sites (FEX), nor were there any differences for all data collected since 1983. "Before" (6/83-4/86) and "after" (5/86-9/88), control (FCD) and impact (FEX) (BACI) analyses showed that there has been an increase in chlorophyll a since the testing of the antenna began. However, lack of differences between sites for the after years coupled with significant positive correlations between water temperature and chlorophyll a and increasing water temperatures during the drought periods in the spring and summer in 1986, 87, and 88 lead us to believe that these differences are related to weather variables and not to ELF exposure.

## 2. Organic Matter

Organic matter (AFDW-biomass) standing crop and accrual rates showed considerable year to year variability similar to chlorophyll *a*. These parameters have been consistently characterized by showing no significant differences between sites since 1983. BACI analyses also showed that no difference has occurred in AFDW-organic matter accumulation since the testing of the antenna began in 1986. The only overall trend has been for a July-August peak in standing crop and accrual rates and winter time lows for both standing crop and accrual. Organic matter standing crop was significantly ( $p < 0.05$ ) correlated primarily with water temperature (positively) and with discharge and dissolved oxygen (negatively). It was also significantly, positively correlated with chlorophyll *a*.

## 3. Chlorophyll a to Phaeophytin a Ratios

This ratio continued to vary widely throughout the year in 1986-87. It proved to be more predictable in 1987-88. Even so, the random nature of the fluctuations appear to indicate that this parameter will not be useful for detection of ELF effects.

## 4. Diatom Cell Density

Diatom cell density continued to be characterized by no statistical difference between sites, regardless of length of data set compared according to paired *t* tests. However, BACI analyses indicated that data collected before 4/86 were significantly different from data collected after 4/86. The increased density after 4/86 may be related to extremely dry conditions during May and early summer in each of these years. Density was highest in ~~May~~ in all three years and was higher in 1988 than in any year prior. The effect of weather was suggested by the significant positive correlation with water temperature. Density was also positively correlated with chlorophyll *a* and negatively correlated with evenness and diversity.

## 5. Species Diversity and Evenness

Diatom species diversity and evenness were not significantly different in 1988 or for all data collected to date according to paired *t* tests. Annual trends show a high diversity and evenness during winter (except winter of 1986-7) and lower values during the summer periods. In 1988, we calculated percent abundance for all species of

diatoms and presented data for all species that achieved dominance greater than 10 % for any season. Only two species, Achnanthes minutissima and Cocconeis placentula, achieve such dominance in the summer, and the same two species have been dominant each summer since the start of the study. From three to five species achieve such dominance in the winter, and these three change from winter to winter. BACI analyses were presented for five species of diatoms and showed that few differences have occurred before and after antenna testing began. Even so, overall diversity and evenness have changed significantly over that time period according to the BACI analyses. Because of the pattern of year to year differences, we suggest that these changes may be related to weather rather than ELF effects.

#### 6. Total Biovolume and Individual Cell Volume

Individual cell volume comparisons of diatoms between sites showed no significant differences according to paired t tests. There were also no differences in before and after data according to BACI analyses. Total biovolume was also not significantly different between sites for 1988 or between before and after data sets. In general, average cell volume was high in winter and low in summer, whereas total biovolume tended to be highest in summer since it is the product of average volume times density. Average cell volume was negatively correlated ( $p < 0.05$ ) with water temperature and positively correlated with total biovolume. Total biovolume was positively correlated with chlorophyll a and negatively correlated with diversity and evenness.

#### 7. Correlation with Environmental Variables

A correlation matrix was generated using all the available data collected from each individual site over the past five year period. Although some water chemistry parameters appeared to influence the biological parameters at one site more than another, there was generally amazing agreement between sites regarding the influences of either environmental factors, or water chemistry constituents. The results of the correlations also agreed with our previously reported analyses using multiple regression analyses. Some of these correlations have been presented in the summary above and were included this year in the discussion of each biological parameter.

## 8. Photosynthesis-Respiration Studies

Net production, respiration, and gross production of the community on rock surfaces did not differ greatly between sites. The lack of significance reported in last year's report between sites for 1984, 1985, and 1986, plus the data from 1987 and 1988, indicate that this parameter may offer a precise means of detecting ELF effects on community metabolism.

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Element 3- Effects of Insect Grazer Populations on Periphyton Communities.

Changes from workplan - None.

Rationale

Small E.L.F. electromagnetic radiation effects on aquatic systems may be unnoticeable, particularly if the impacts concern only very small, microscopic single celled algae species. If, however, these same impacted algae species are important food sources for selectively feeding stream grazers, severe disruptions of the trophic linkages within the system could occur. Restructuring of the species composition of the autotrophic community, leading to dominance by non-selected, non-palatable, or non-digestible algal species might be one such consequence. This could result in reduced growth, or lower overall production of benthic grazers. Thus, an essential invertebrate food source of predatory fish species might be significantly reduced.

Additionally the potential may exist for E.L.F. electromagnetic radiation to cause behavioral changes in the grazers themselves. This might result in changes in feeding activity by increasing or decreasing feeding rates or otherwise changing "typical" grazer feeding behavior.

Little is currently known about interactions between stream herbivores (grazers) and the attached algal community in freshwater systems. Most research on freshwater herbivore-algal interactions has been conducted in either ponds (Kesler 1981, Hunter 1980) or in laboratory streams (Colletti et al. 1987, Kehde and Wilhm 1972, Sumner and McIntire 1982). Many of these studies have only documented grazer induced changes in periphyton standing crop, either by extracting chlorophyll *a* or by measuring accumulations of organic matter as ash free dry weight (AFDW). These measures provide only gross approximations of herbivore effects on the total periphyton community. These techniques provide little or no information on the dynamics of the algal species interactions in the presence or absence of herbivores. Ecological studies on the species responses of the algal community to aquatic herbivory have been largely ignored. Only a few studies have attempted to evaluate the effects of herbivores by examining other algal responses besides changes in levels of chlorophyll *a* or organic matter accumulation in the algal community. These include the studies of Lamberti and Resh (1983) on the impact of grazing by the trichopteran larva, *Helicopsyche*. They measured algal turnover rates as

well as chlorophyll a levels and noted that grazing resulted in an attached algal community consisting predominantly of a diatom monolayer. When Helicopsyche were excluded, the algal community changed from a diatom film to a thick growth of filamentous green algae. Eichenberger and Schlatter (1978) found that grazing by Chironomidae in a stream channel maintained a mixture of filamentous green algae and diatoms. Exclusion of chironomid grazers from a second channel resulted in succession proceeding from filamentous green algae to blue-green algae. These studies have demonstrated that grazers can alter the succession of algal species on substrates. Dickman and Gochbauer (1978) indicated that grazer pressure in a stream prevented members of the algal genus Cocconeis from out-competing other algal species. This reduced competition may have increased the establishment of other algae and led to overall greater algal species diversity on the grazed substrates. Grazing mayflies (Ameletus validus) confined to in situ plexiglass flow-through chambers in a California stream for 23 days significantly reduced periphyton biomass (Hill and Knight 1987). In addition, members of the loose periphyton layer were disproportionately reduced in relative abundance while members of the tightly adhered adnate layer increased in relative abundance. To our knowledge, no detailed study of the effects of grazing on periphytic algal species occurrence and abundance in lotic systems other than that by Hill and Knight (1987) or Colletti et al (1987) has been conducted.

Several studies have documented the effects of algal distribution on intra- and inter-specific competition among grazers (Hart 1983, McAuliffe 1983, 1984, Wiley and Kohler 1984). These studies indicated that periphyton abundance and patchiness are important determinants of grazer distribution and abundance. Recent work on the Ford River by Webb and Merritt (1987) (included in the 1987 annual report; AE-058) on the importance of periphyton to the growth of the grazing mayfly Stenonema vicarium (Walker) also supports the importance of further investigations into determining the magnitude of grazing induced changes on the algal community and measuring the impact of grazing on altering the composition of this nutritionally important food source. Our hypothesis is that grazer abundance is an important determinant of the structure of the attached algal community, and that the consequences of grazing can dramatically alter the algal species abundances in the periphyton.

Larvae of the trichopteran, Glossosoma nigrior (Banks) are known to be specialized grazers (Cummins 1973, Oemke



1983). Recent investigations of in situ food selections by various instars of the larvae (Oemke 1984) indicated that small, unicellular algal forms were more often ingested than were large, stalked or filamentous types of diatoms. Those diatom species which were preferentially ingested by grazing larvae sometimes showed significant differences between gut contents abundances and abundances of the surrounding periphyton community. Similarly, work by Hill and Knight (1987) indicated that mayfly grazing altered the community structure of the diatoms present. Thus, we hypothesized that grazing by Glossosoma would lead to reduced abundances of small growth forms of selected diatom species, like Cocconeis placentula var. euglypta and var. lineata, which are known to dominate the algal flora during the summer months (Oemke and Burton 1986) and to a concomitant increase in abundance of other non-selected diatom species or algal growth forms in the periphyton algal community.

#### Objective

The behavior of typical grazing invertebrates and their impact on the diatom community were determined to provide the data necessary for linking invertebrate herbivores to the periphyton community based on trophic level analyses. This objective included the determination of the effects of various levels of herbivory on periphyton community dynamics. The ultimate objective will be to determine whether or not E.L.F. electromagnetic radiation affects the interaction between grazing macroinvertebrates and their "prey", the benthic algae.

#### Materials and Methods

Small microcosm streamside flow-through artificial streams were used for monitoring effects of grazers on periphyton. These plexiglass streams were constructed from 1.27 cm thick plexiglass and were 1 m long with three 15 cm wide channels fed from a common reservoir. This reservoir was filled by pumping water from the Ford River through a 300 micron mesh filter into the reservoir. The reservoir also contained polyester fibers as an additional filter to remove suspended sediments. This double filter system proved necessary because of excessive settling of suspended particles on substrates in its absence. The pumps were powered by a heavy duty, marine 12 volt battery, which was exchanged and recharged daily. Two of these streams were constructed so that identical studies could be conducted at both FEX and FCD sites simultaneously.

Each set of streamside channels was fed from a common water source, and the three channels were subdivided into four chambers per channel using plastic screen dividers (Fig. 3.1). Since all three channels were fed from a common water source, the 12 chambers represented 12 replicates. This design duplicated use of 12 separate chambers placed in the Ford River and avoided the problem of pseudoreplication as much as possible given the need to use the Ford River as a common water source. Use of additional stream channels would simply increase the replicates without solving the problem of the common water source. In 1987 and 1988, only 6 of these chambers were used per stream (3 controls and 3 experimental chambers), since we concluded that only one grazer level was needed and since the 6 middle chambers had more uniform flow and depth conditions than did the other 6.

Ceramic tiles (3.6 cm<sup>2</sup>) were placed in the river 25-30 days prior to experiments to allow time for algal colonization. Twenty randomly selected tiles were then placed in one of the four separated chambers along each of the three channels of the artificial streams. Each chamber was separated from the next by plastic screen with fine mesh to prevent exchange of grazers between chambers. Tiles were taken at random from each control and treatment chamber at the end of each experiment for determination of chlorophyll *a*, (n=8 per chamber), organic matter biomass (n=8), and diatom species determinations (n=4). Each level of grazing was always replicated at least three times. The colonized tiles were exposed to grazing for a total of 6 or 7 days (usually 7 except in 1986 when a storm event caused the experiment to be terminated one day earlier than planned).

In 1985 the 12 treatment chambers had three levels of grazing assigned to them in a random fashion and represented a randomized block design. The grazing levels chosen were: (1) no grazers, (2) a grazing level which represented about the average level of grazers found in favorable habitats in the Ford River (e.g. shallow, rapid current areas of the Ford for *Glossosoma*), and (3) a grazing level about double the average rate of grazing in the Ford (these levels were 0, 15, and 30 *Glossosoma* per chamber for the primary experiment). The results of this study were presented in the 1987 annual report and are the subject of a paper to be submitted to the Journal of the North American Benthological Society (This paper will be appended to the next annual report).

In 1986, the studies at FEX contrasted the effects of grazing by limpets with the effects of grazing by the insect larva, *Glossosoma*. The results of this study were presented

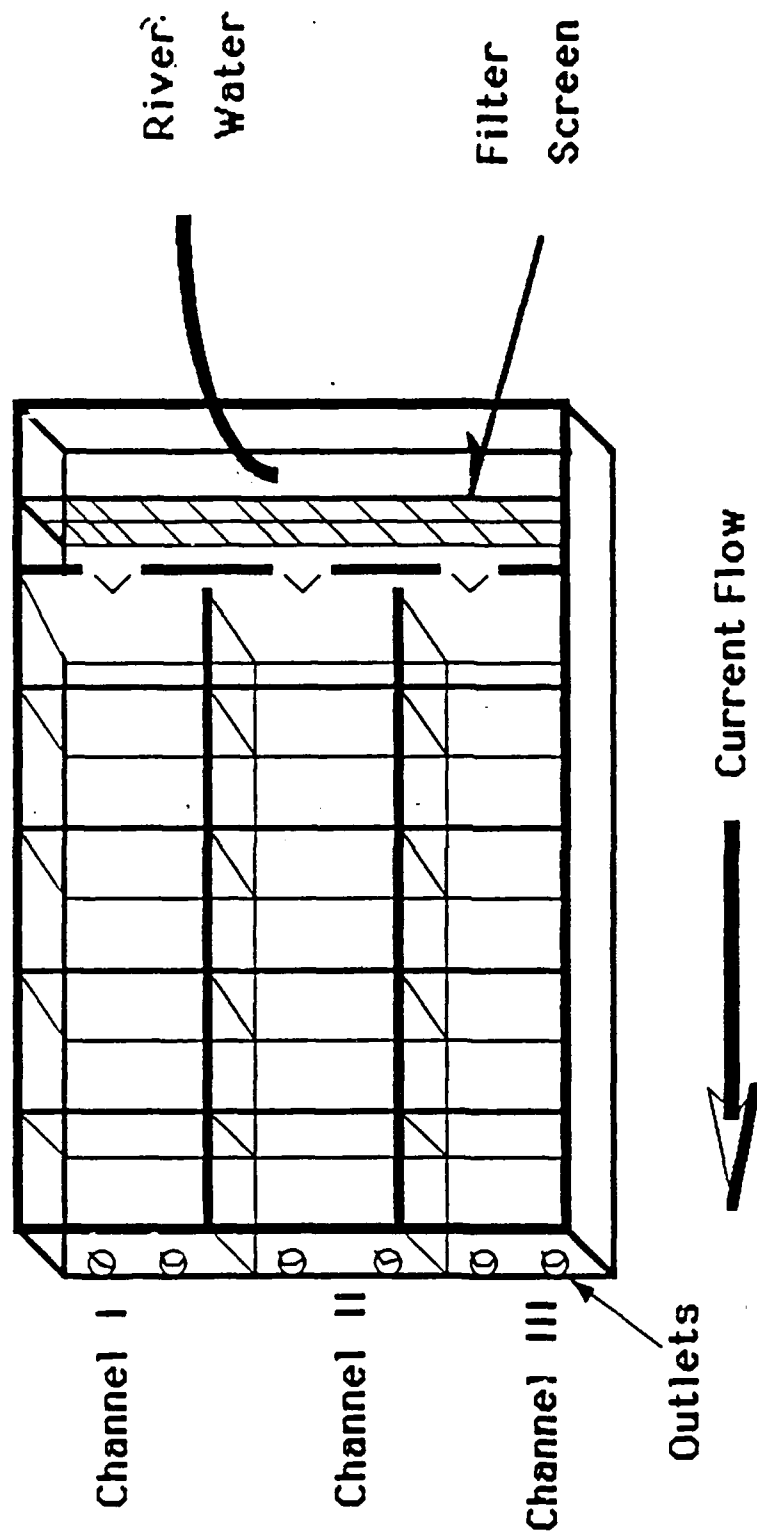


Figure 3.1 Experimental stream used in grazer studies.  
Not drawn to scale.

in the 1987 annual report (AE-071). We plan additional analyses of these data and will include them in future annual reports.

In both 1987 and 1988, two levels of tricopteran larvae grazer (Glossosoma nigrum) were used (0 and 30 per chamber). The results of the 1987 study are discussed in full here and preliminary results on the effect of grazing on chlorophyll *a* and organic matter standing crop from the 1988 study are presented. Counts of attached algae on the slides from 1988 have not yet been completed.

## Results and Discussion

### A. The 1988 Study

While the final detailed analyses of diatom species counts remain to be completed for these experiments, the data are relatively complete for the comparisons of AFDW-biomass between the two sites (Table 3.1). Three level nested ANOVA comparisons using results from both sites showed significant differences between FEX and FCD AFDW-organic matter accumulation (Table 3.2). Within a site however, comparing treatments at FEX separately from treatments at FCD, no significant differences were detected between AFDW-organic matter accumulation of control against grazed tiles i.e. between control and grazed tiles at FEX and between control and grazed tiles at FCD.

Chlorophyll *a* comparisons indicated no significant differences between sites or treatments (Table 3.2). Thus, no overall clear evidence for grazing significantly altering either chlorophyll *a* or AFDW-organic matter accumulation levels was evident for the 1988 experiments.

Chlorophyll *a* and AFDW-organic matter accumulation levels appear not to be very sensitive to grazing induced changes. This may be particularly noticeable in short term experiments run over the course of several days. The same results may not occur in grazing experiments allowed to continue for several weeks. Hill and Knight (1987) observed significant reductions in AFDW-organic matter accumulation and increases in chlorophyll *a* after 23 days of grazing pressure. This pattern of ambiguous results for significant and consistent changes in either chlorophyll *a* or AFDW-organic matter accumulation levels as a result of grazing, is precisely the pattern observed in all previously

Table 3.1 Means  $\pm$  S.E.'s of Organic matter (AFDW, g/m<sup>2</sup>) and Chlorophyll *a* (mg/m<sup>2</sup>) from initial, grazed and ungrazed treatments in the 1988 grazer experiment. N's is parentheses.

FCD

Parameter	Initial		Grazed		Ungrazed	
Organic Matter	1.87 $\pm$ 0.45	(8)	3.37 $\pm$ 0.42	(3)	3.28 $\pm$ 0.55	(3)
Chlorophyll <i>a</i>	6.64 $\pm$ 0.53	(8)	9.00 $\pm$ 0.20	(3)	9.17 $\pm$ 0.53	(3)

FEX

Parameter	Initial		Grazed		Ungrazed	
Organic Matter	3.73 $\pm$ 0.18	(8)	4.97 $\pm$ 0.62	(3)	5.15 $\pm$ 0.19	(3)
Chlorophyll <i>a</i>	7.68 $\pm$ 0.66	(8)	10.00 $\pm$ 0.59	(3)	9.11 $\pm$ 0.47	(3)

Table 3.2 Results of 3 level nested ANOVA test on 1987 and 1988 Biological parameters from the grazer studies.

Year Parameter	Source of Variance (level)		
	Among Sites (FEX and FCD)	Among Treatments (Grazed and Ungrazed)	Among Replicates ( 3 replicates/Treatment)
1987			
Organic Matter	P < 0.05	NS	NS
Chlorophyll a	NS	NS	NS
Evenness	P < 0.05	NS	P < 0.01
Diversity	NS	NS	NS
Cell Density	P < 0.05	NS	NS
Cell Volume	NS	NS	P < 0.01
Total Biovolume	NS	NS	NS
1988			
Organic Matter	P < 0.01	NS	P < 0.05
chlorophyll a	NS	NS	NS

run experiments (see Annual Reports AE-045, AE-058, and AE-071 for 1985, 1986 and 1987). More precise examination of species composition changes due to grazing for the 1988 experiments (similar to what follows for the final analysis of the 1987 experiments and to what was reported previously for the 1985 and 1986 experiments) may ultimately show a pattern of predictable and significant change.

#### B. The 1987 Study

These experiments were conducted at the same time period in August at both FEX and FCD for no grazer versus 30 Glossosoma per chamber comparisons (0 versus double the "average" grazer levels in the Ford River). Chlorophyll a levels and AFDW-organic matter accumulation levels were not significantly different between any Glossosoma and control treatments within a site (Tables 3.2, 3.3).

Several different aspects of diatom community structure were measured or calculated. These included the Shannon-Wiener index of species diversity, Simpson's index of evenness, as well as determinations of cell density, average individual cell volume, and total biovolume (average cell volume times density-this is a crude index of algal biomass). There were no significant differences for any of these parameters as a result of grazing (Tables 3.2 and 3.3). The three level nested ANOVA indicated that there were significant site differences between FCD and FEX for the parameters: organic matter biomass, evenness and cell density (Table 3.2). There were also significant differences for evenness and cell volume among the replicates in each treatment (Table 3.2).

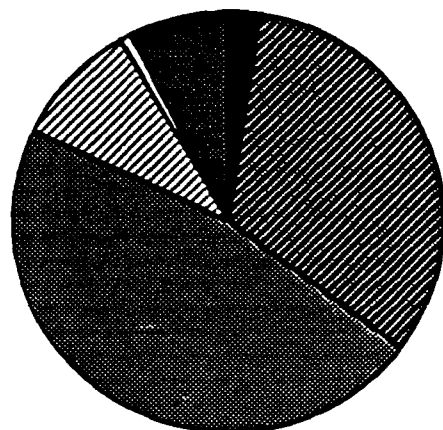
In 1985, there were significant differences in community composition as a result of grazing with the relative abundance of Achnanthes minutissima minutissima (previously referred to as A. affinis) significantly increased in the grazed treatments and this trend was repeated (though not quite significantly) in 1986. Increases in the relative abundance of Achnanthes were accompanied by decreases in the relative abundance of Cocconeis. The 1987 data did not corroborate these previously described trends. The proportions of each of the 5 most dominant species showed little change as a result of grazing (Fig. 3.2). These proportions were arcsine transformed and examined using a three level nested ANOVA (Table 3.4). In 1987 there were no

Table 3.3

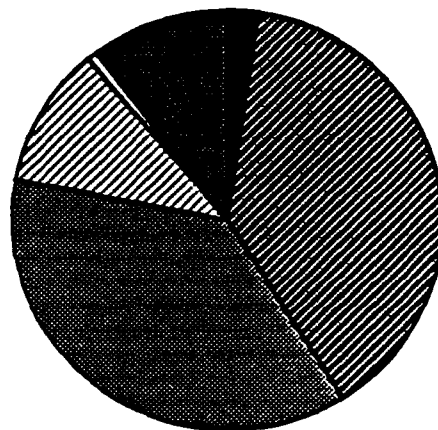
Means  $\pm$  S.E., of Biological Parameters measured from the Glossosoma grazer study in 1987. Organic matter = g/m<sup>2</sup>, Chlorophyll a = mg/m<sup>2</sup>, Cell density = cells/m<sup>2</sup>  $\times 10^8$ , Cell volume = microns<sup>3</sup> and total Biovolume = microns<sup>3</sup>/m<sup>2</sup>  $\times 10^{-11}$  N's = 3.

Parameter	FCD		FEX	
	Grazed	Ungrazed	Grazed	Ungrazed
Organic matter	1.90 $\pm$ 0.18	2.26 $\pm$ 0.29	3.41 $\pm$ 0.20	3.71 $\pm$ 0.48
Chlorophyll <u>a</u>	6.13 $\pm$ 0.56	5.91 $\pm$ 0.41	6.48 $\pm$ 0.25	7.48 $\pm$ 0.51
Evenness	0.56 $\pm$ 0.01	0.60 $\pm$ 0.03	0.66 $\pm$ 0.04	0.65 $\pm$ 0.03
Diversity	1.23 $\pm$ 0.09	1.53 $\pm$ 0.04	1.89 $\pm$ 0.15	1.89 $\pm$ 0.11
Cell Density	29.69 $\pm$ 1.03	29.14 $\pm$ 6.35	31.11 $\pm$ 2.53	31.54 $\pm$ 4.11
Cell Volume	185.84 $\pm$ 4.95	174.67 $\pm$ 5.39	191.60 $\pm$ 12.14	180.33 $\pm$ 4.72
Cell Biovolume	5.96 $\pm$ 0.68	5.02 $\pm$ 0.94	6.06 $\pm$ 0.84	5.64 $\pm$ 0.65

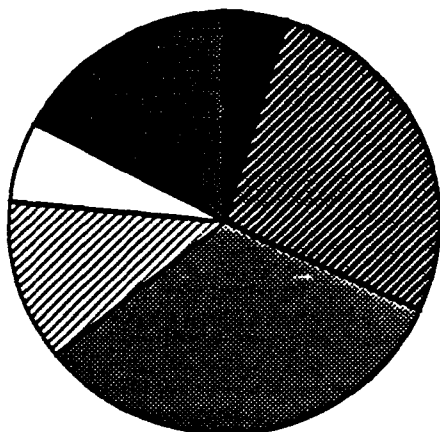




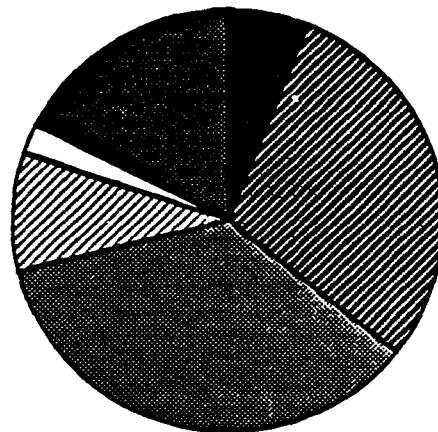
**FCD GRAZED**



**FCD UNGRAZED**



**FEX GRAZED**



**FEX UNGRAZED**

■ *A. linearis linearis*  
 ▨ *A. minutissima minutissima*  
 ▩ *C. placentula placentula*

▤ *C. placentula lineata*  
 □ *G. parvulum parvulum*  
 ■ OTHERS

**FIGURE 3.2 PROPORTION OF TOTAL COMMUNITY COMPOSITION OF THE FIVE MOST DOMINANT DIATOM SPECIES ON GRAZED AND UNGRAZED TILES FROM THE 1987 GRAZER STUDY**

Table 3.4 Results of 3 level nested ANOVA performed on Arcsine transformed proportions of the five most dominant diatom species on grazed and ungrazed tiles at FEX and FCD for the 1987 Grazer study.

Species	Source of Variance		
	Among Sites	Among Treatments	Among Replicates
<u>Achnanthes linearis</u> var. <u>linearis</u>	P < 0.05	NS	P < 0.05
<u>Achnanthes minutissima</u> var. <u>minutissima</u>	NS	NS	P < 0.01
<u>Cocconeis Placentula</u> var. <u>placentula</u>	NS	NS	P < 0.01
<u>Cocconeis Placentula</u> var. <u>lineata</u>	NS	NS	P < 0.01
<u>Gomphonema Parvulum</u> var. <u>parvulum</u>	NS	NS	NS

significant changes in the relative abundance of A. minutissima (0.33 and 0.39 on grazed and ungrazed tiles at FCD and 0.27 and 0.29 on grazed and ungrazed tiles at FEX). The cause of this discrepancy between years is unknown but may be related to siltation problems encountered during the course of the experiments. A heavy rainfall at the start of the 1987 experiment substantially increased the discharge and turbidity of the Ford River for the first few days of the experiment. An examination of the field notes from this study indicated that both sites experienced "heavy silt buildup" for the first four days of the experiment. In contrast, during the 1985 and 1986 experiments, siltation was slight or nonexistent. Heavy silt build up may have limited the ability of the grazer to get to the diatom layer on the tiles. As recent studies similar to ours (Hill and Knight 1987) have observed patterns similar to those we observed in 1985 and 1986, it seems reasonable to attribute the lack of any significant grazer effect in the 1987 study to the siltation problem experienced during the course of the study. Unfortunately, the 1988 drought ended the day the 1988 grazer study was started resulting in siltation problems for the first several days of the study. In the future, we hope to avoid this problem by placing enough tiles in the river for colonization to run several grazer studies. This will give us extra tiles to fall back on should we have to abort and restart the experiment due to an untimely storm event.

We also decided to try a principal components analysis approach to the 1987 data in the hopes that this approach might reveal more subtle differences than had been detected using the nested ANOVA analyses reported above. Principal component analysis was performed on a covariance matrix of arcsine transformed proportional community data using SYSTAT, a statistical software package (Wilkinson, 1986). The first principal component explained 74.5 % of the variance in the data. This component was primarily defined by the inverse relationship between Cocconeis placentula and Achnanthes minutissima. The Pearson Product Moment Correlation coefficient between abundances of these two species was -0.599 ( $p < 0.001$ ). Both species were dominant in all 48 samples. These phenomena, high abundances of Cocconeis and Achnanthes and an inverse relationship between them, have also been noted in other studies (Brown and Austin 1973, Molloy 1988). This first principal component showed no relationship to site or grazer treatments, but was 98 % explained by chamber effects nested within grazer and site treatments (nested ANOVA).

The second principal component accounted for 15.2 % of the variance in the data. This component highlighted differences between the two sites, FEX and FCD (73 % of variance explained by site and 20 % of variance explained by chamber effects-nested ANOVA of site, grazer, and chamber effects). Five taxa loaded heavily (high covariance) on this component. Achnanthes linearis, Cocconeis placentula v. lineata, and Gomphonema parvulum comprised a greater portion of the communities at the FEX site, while Achnanthes minutissima and Cocconeis placentula were more common at the FCD site.

The principal components analysis did lead to some additional insights into the causes of the differences observed with the overall nested ANOVA analysis but did not change the overall conclusions. We expect to use this same type of analysis to examine all the experimental results from 1985 through 1988 and will report these analyses in future annual reports.

We are still left with the conflicting results from 1985 and 1986 with grazer effects appearing to be important in structuring the diatom community and the results from 1987 where grazing does not appear to be important. In 1989, we will repeat these experiments making sure that they are conducted between storm events with low rates of siltation. We may also opt to alter our design slightly to reduce siltation by incorporating a sediment settling basin between the stream and the flow-through streamside channels. We will also try to increase the length of exposure to the grazers from 7 to 14 days and may opt to increase grazer density. The 14 day experiment will include enough replication to enable sampling at both the 7 and 14 day points in time. These procedures will insure that we can examine the effects of ELF electromagnetic radiation on benthic algal communities that are already stressed by high levels of grazing activities.

#### Summary

Grazing macroinvertebrates can change the composition of the diatom community at densities equal to or greater than densities found in the Ford River. Specifically, Glossoma nigrum, a grazing caddisfly, caused a shift in dominance within the diatom community in 1985 and 1986 with Cocconeis decreasing in abundance and Achnanthes increasing in abundance as grazing pressure increased. Such shifts in

community structure occurred at both FEX and FCD despite no significant changes in community based parameters such as chlorophyll *a* or AFDW-organic matter biomass accumulation. Results from 1985 were somewhat different from results from 1986. In 1986, the trend towards decreased abundance of Cocconeis and increased abundance of Achnanthes occurred at both sites but was not as significant as in 1985. In 1987, there was no measurable impact of grazers on any aspect of the periphyton community with the possible exception of shifts in dominance of a couple of minor taxa at FEX. Between year differences in the impact of grazers on the periphyton communities in our streamside channels may be due to variation in the silt load encountered during the course of the studies. We plan some minor modifications in procedures to avoid such potential confounding problems in the future.

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#### Element 4 - Species Richness and Biomass of Stream Insects from Artificial Substrates in Riffles

Changes from the Original Synopsis - None.

##### Objectives

1) To monitor structural (diversity, evenness, richness, numbers of individuals) and functional community parameters (total biomass, biomass according to functional feeding groups) for benthic insect fauna from July 1983 to August 1988 at FEX and FCD sites; 2) to monitor changes in size classes of selected insects over that period at FEX and FCD, and 3) to determine whether changes at the experimental site, FEX, are matched by similar changes at the reference site, FCD, before versus after activation of the E.L.F. lines.

##### Rationale

Extremely low frequency waves may alter structural and functional community parameters (A.I.B.S. 1985, Greenebaum et al. 1979, Halberg et al. 1975) as well as life histories of insects (Walters and Carstensen 1986, Greenberg and Bindokas 1981). In looking for potential effects, seasonal changes in numbers of individuals for each species, total biomass of the insects in each sample, and biomass of functional feeding groups are enumerated (after Merritt and Cummins 1984). Life histories of some insect species may be very sensitive to ELF effects, and so changes in size classes of selected aquatic insects are followed. Size classes, determined by the ratio mean dry weight per individual (MDW/IND) are being monitored for selected aquatic insects. We selected species based on the following criteria: 1) large population sizes, 2) discrete generation times, and 3) members of functional feeding groups hypothesized as responding to ELF effects on food resources such as periphyton levels. Data are available for all taxa identified. If it appears that additional, possibly more rare species are being affected, the data are available for computation of MDW/IND values over time at both sites.

##### Materials and Methods

From 1983 through 1988 60  $\mu$ m mesh-lined half cylinder 18 x 28 x 10 cm substrate sample baskets were filled with benthic substrata and buried flush with the stream bottom at FEX and FCD. From May through September each year, seven replicates for each site were collected monthly, with replacement. Each September, sufficient samplers were placed at the sites to allow for late fall, winter, and early spring collections. (After 1986, January through March collects were excluded, owing to past sampling difficulties.) Meier et al. (1979) showed that in southern Michigan 30 to 39 days' incubation of samplers in substrates showed the maximum numbers



of individuals colonizing substrates. Our colonization studies (1983, 1984 Annual Reports) showed that 30 days' incubation showed the maximum number of taxa and individuals.

Samples were processed by placing samplers in separate buckets, washing substrata thoroughly and retaining the suspended animals in a 60  $\mu$ m mesh soil sieve. Animals were preserved in 80% ethyl alcohol. In the laboratory, insects were picked from detritus and then separated to order level. Specimens were identified to the lowest taxon possible and then were measured to the nearest mm. for biomass estimates (after Smock, 1980). Numbers of individuals, taxon diversity ( $H'$ ), taxon richness ( $S$ ), evenness ( $J'$ ) and percent numerical dominance for selected species were determined for each sample. Total sample biomass, biomass for functional feeding groups (after Merritt and Cummins, 1984) and mean dry weight per individual (MDW/IND) values were computed. Statistical analyses included power tests, coefficient of variation values, Student-t tests, linear regression analyses, 2-Way ANOVA tests, correlation coefficient values, and percent dominance of chironomids. MDW/IND values were computed for insects that had high numerical abundances. Those were: Chironomidae, Paraleptophlebia mollis, Ephemerella invaria, E. subvaria, Optioservus sp., Glossosoma nigrior and Protophila sp. A list of all taxa collected at FEX and FCD appears in Appendix I.

## Results and Discussion

### Structural Community Indices

Diversity ( $H'$ , after Shannon-Weiner), evenness ( $J'$ ), taxon richness ( $S$ ) and numbers of individuals showed consistent depressions during winters and early springs and peaks during the summer months throughout the study (figures 4.1A, 4.1B, 4.2, 4.3A, 4.3B). In 1986 and 1987, summer peaks for  $S$  (Figure 4.2) and numbers of individuals (figures 4.3A, 4.3B) lasted longer. Afterward, they did not drop to the autumn and winter levels as for prior years. These differences may be related to the unusually mild winters of 1986 and 1987 as well as to low discharge values over the two summers.

Both water temperatures and discharge values were correlated with  $H'$  and  $S$  at each site from April through October each year (Table 4.1). However, water temperature was more highly correlated with  $H'$  at FCD than it was at FEX.  $H'$  falls to low levels during winter and early spring months at FCD as compared with FEX (Figure 4.1A). The lower winter and early spring water temperatures, thus, were more highly correlated with diversity at FCD than at FEX.

In 1986, 1987 and 1988 when few months included periods of heavy rains or high discharge values, taxon richness and

FIGURE 4.1A DIVERSITY, FEX AND FCD 1983-1988

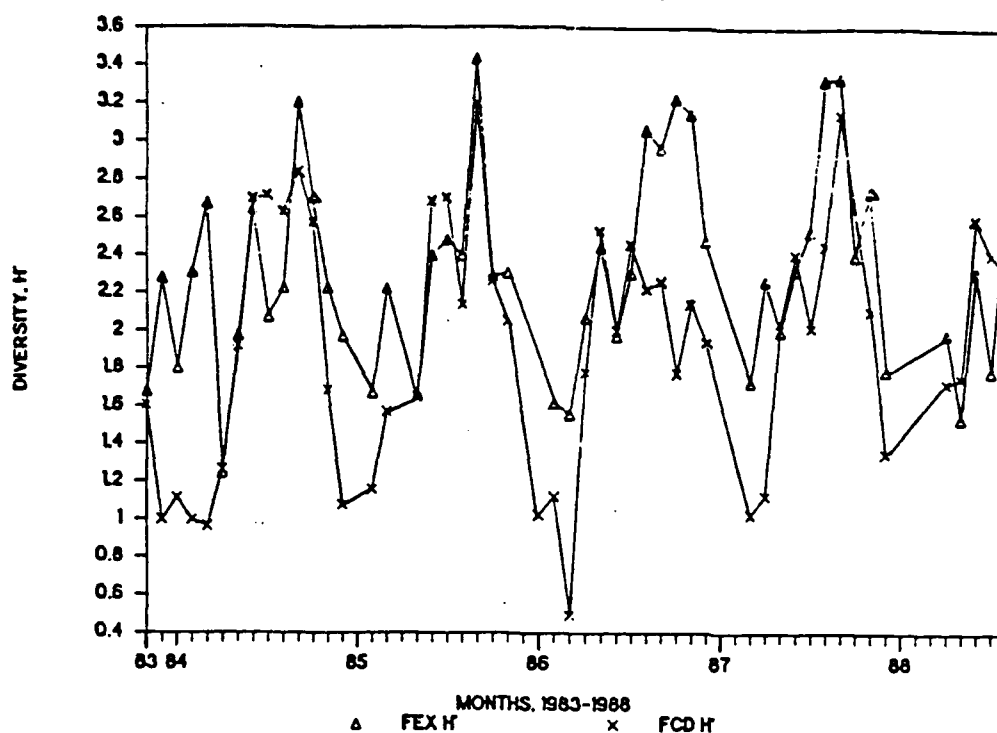


FIGURE 4.1B EVENNESS, FEX AND FCD 1983-1988

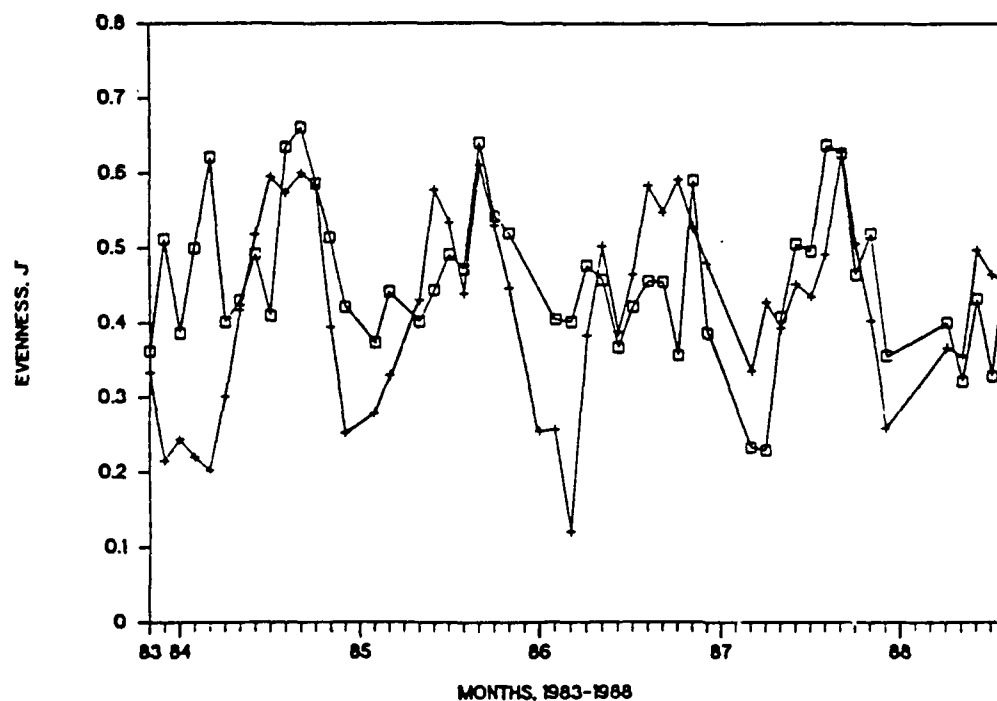


Figure 4.1A. Mean Diversity ( $H'$ ) at FEX and FCD, November, 1983 to August, 1988. Triangles = FEX, crosses = FCD.  
 Figure 4.1B. Mean Taxon Evenness ( $J'$ ) at FEX and FCD, November, 1983 to August, 1988. Triangles = FEX, crosses = FCD.

FIGURE 4.2

# RICHNESS, FEX AND FCD 1983-1988

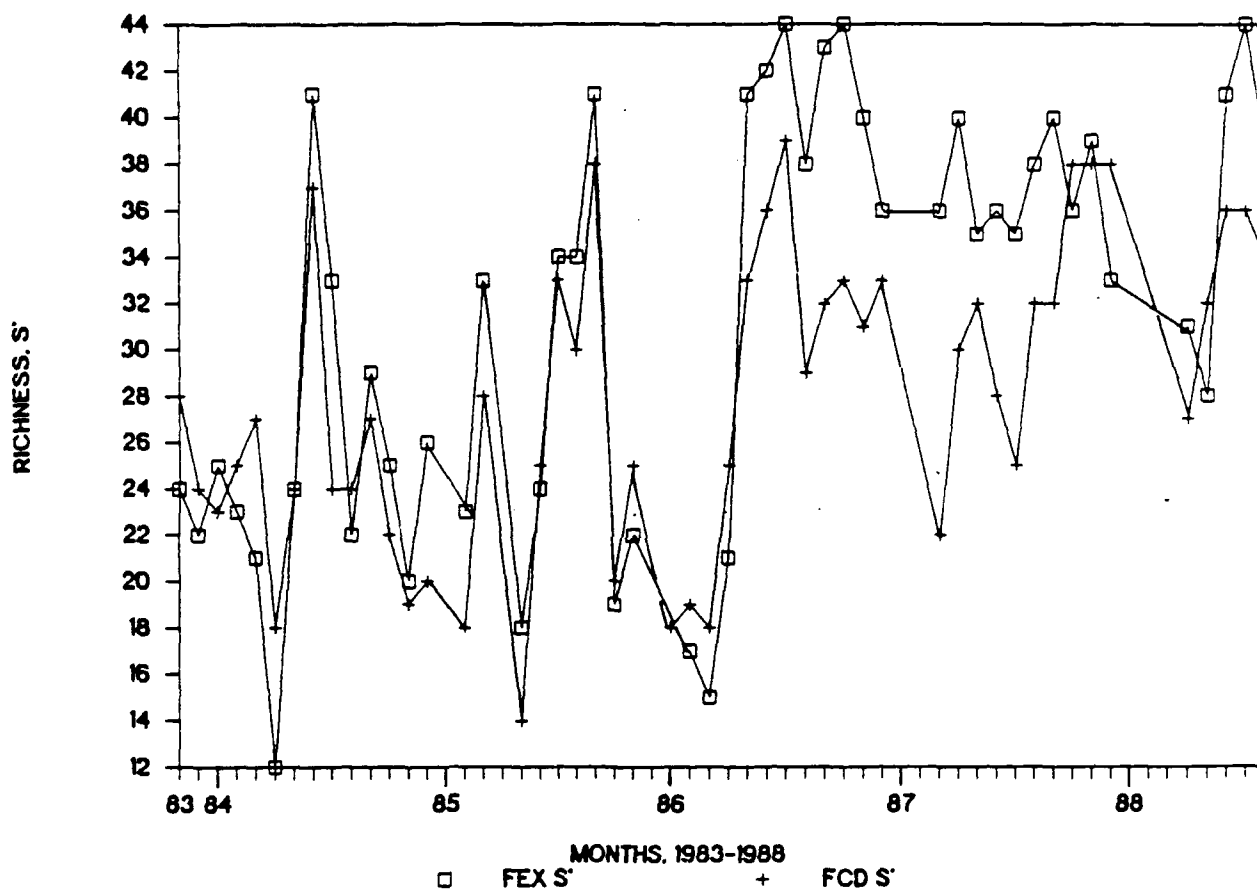


Figure 4.2. Mean Richness (S') at FEX and FCD, November, 1983 to August, 1988. Squares = FEX, Pluses = FCD.

FIGURE 4.3A ALL INDIVIDUALS VS. CHIRONOMIDS ONLY

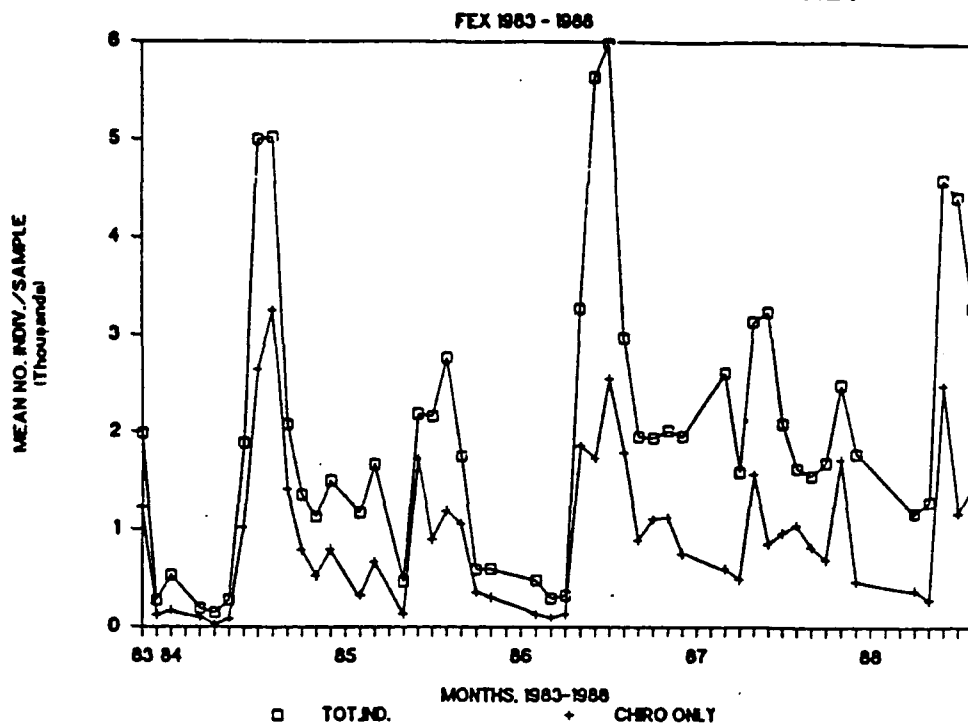


FIGURE 4.3B ALL INDIVIDUALS VS CHIRONOMIDS ONLY

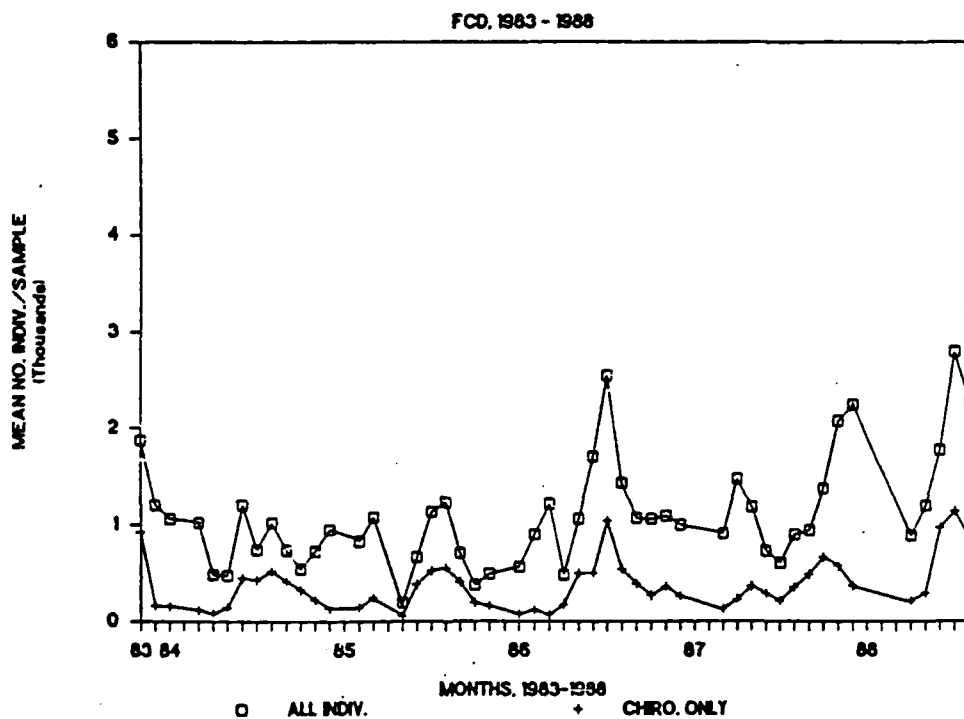


Figure 4.3A. Mean Number of Individuals (squares) versus mean number of Chironomids (pluses) at FEX, November 1983 to August, 1988.

Figure 4.3B. Mean Number of Individuals (squares) versus mean number of Chironomids (pluses) at FCD, November 1983 to August, 1988.

numbers of individuals remained consistently higher than in 1983, 1984 and 1985. The mild winters could have resulted in insects remaining in surficial sediments when they may otherwise go to deeper layers or to other more protected sites where our samplers do not occur. During summers of low rainfall and low discharge, insects that might otherwise be dislodged or move deeper into substrates during periods of high discharge could be collected from the samplers. The FEX site received some low intensity, intermittent ELF exposure in the summers of 1986 (ca. 4 amps), 1987 (ca. 15 amps) and 1988 (higher than for 1986 and 1987 with longer exposure times).  $H'$ ,  $S$  and Numbers of individuals have been usually higher at FEX than at FCD. Those variables showed higher values at both sites in 1986 and 1987 (figures 4.1A, 4.1B, 4.2, 4.3A, 4.3B). The mild winters and low summer discharges in 1986 - 1988, rather than ELF activation appears to have affected  $H'$  and  $S$  at the two sites. Relationships between environmental variables and biological variables at the two sites must be determined to separate natural, environmental effects from ELF effects. Some of these relationships are described at the end of this section on structural community parameters.

TABLE 4.1

Correlation Matrix for Water Discharge, Water Temperature,  $H'$  and  $S$  at FEX and at FCD, July 1983 - August 1988\*

	FEX		FCD	
	Discharge	Water Temp.	Discharge	Water Temp.
$H'$	-.340	.258	-.410	.614
$S$	-.588	.328	-.565	.264

Critical value (1-tailed, .05) = + or - 0.27

Critical value (2-tailed, .05) = + or - 0.32

\* Discharge values are available only from April through October each year; the correlations exclude December through March data.

$J'$  and  $H'$  values are affected by changes in numerical dominance of the family Chironomidae (See figures 4.3A and 4.3B and Table 4.2). We identify the many chironomids in substrates to family level, owing to the time constraints. Therefore, if percent dominance of chironomids increases, evenness and diversity will go down. In order to determine the affect that chironomids have on structural community parameters, they were computed with and without chironomids at each site. Differences in means and standard deviations for  $H'$  and  $J'$  with and without chironomids appear in Table 4.2.

The impact of chironomids, taken as a unit, on  $H'$  and  $J'$  means at FEX and FCD is obvious. Because chironomids are more common relative to other taxa in substrate samples from FCD as compared with samples from FEX (Figs. 4.3A, 4.3B) the impact was greater at that site. FCD contains more sand and lacks the quantity of pebbles found at the FEX site. The higher number of insects at FEX relative to chironomids may be attributable to the more heterogeneous nature of the substrate there (See 1983 Annual Report). These differences points up the fact that the two sites are not sufficiently similar to make assumptions based on a true experimental and a control situation as is usually found in laboratory experiments. Physical variables between the two sites have to be factored into analyses to allow detection of any potential ELF effects.

TABLE 4.2

Descriptive Statistics for  $H'$  and  $J'$ , With and Without Chironomids in Substrates (ArcSine Transform for  $J'$ )  
November 1983 through August 1988.

Site and Parameter	Descriptive Statistics			
	Mean	S.D.	Minimum	Maximum
FEX				
$H'$ , with chironomids	2.323	0.538	1.246	3.413
without chironomids	3.181	0.667	1.308	4.425
FCD				
$H'$ , with chironomids	1.987	0.639	0.497	3.200
without chironomids	3.354	0.506	1.503	4.199
-----				
FEX				
$J'$ , with chironomids	43.54	5.36	34.57	54.39
without chironomids	53.98	9.11	32.71	67.49
FCD				
$J'$ , with chironomids	39.65	7.41	20.27	52.24
without chironomids	57.54	5.30	34.14	64.38
-----				
Percent Chironomid Dominance				
FEX	48.37	8.48	28.52	62.94
FCD	54.25	9.62	36.39	76.19

In order to see whether the differences in mean values for  $H'$  and  $J'$  affected correlation coefficients (C.C.) among the structural community parameters, C.C. values were computed with and without chironomids. Table 4.3 presents those results.

In general, correlation coefficients for  $H'$  versus  $J'$  and for  $S$  versus  $J$  for each site were only slightly higher when chironomids were included in the analysis. Thus, although means for each parameter differed, depending on whether or not chironomids were included, correlation coefficients between the two sites did not differ. There was, however, a large impact on  $H'$  and  $J'$  within sites. At FCD, percent dominance of chironomids correlated highly with  $H'$  and  $J'$  (C.C. = -0.86, -0.88, respectively). Although C.C. values were significant at FEX for  $H'$  and for  $J'$  as related to percent dominance of chironomids (-0.67 and -0.70 respectively) they were not as highly correlated as at FCD.

TABLE 4.3

Correlation Matrix for Structural Community Parameters.  
Insects in Substrates, November, 1983 through August, 1988  
(ArcSine transformation for  $J'$  and % Chironomids)

With Chironomids

	FEX S	FCD S	FEX $H'$	FCD $H'$	FEX $J'$	FCD $J'$	FEX % Chironomid Dominance	FCD
FEX,S	1.00							
FCD,S	.84	1.00						
FEX, $H'$	.53	.45	1.00					
FCD, $H'$	.51	.52	.61	1.00				
FEX, $J'$	.12	.13	.90	.46	1.00			
FCD, $J'$	.35	.32	.55	.96	.47	1.00		
FEX, %Chironomids			-.67	-.57	-.70	-.56	1.00	
FCD, %Chironomids			-.43	-.86	-.35	-.88	-.59	1.00

Without Chironomids

	FEX S	FCD S	FEX $H'$	FCD $H'$	FEX $J'$	FCD $J'$
FEX,S	1.00					
FCD,S	.84	1.00				
FEX, $H'$	.55	.39	1.00			
FCD, $H'$	.57	.61	.60	1.00		
FEX, $J'$	.08	.01	.84	.41	1.00	
FCD, $J'$	.13	.12	.50	.82	.55	1.00

Critical value (1-tail, .05) = + or - .240

Critical value (2-tail, .05) = + or - .284

Mean numbers of individuals per sample peaked at FEX in May - June each year (Fig. 4.3A). Because chironomids comprise a large percentage of individuals each month, their total mean numbers were also included in the figure to show that other taxa as well increased during late spring and early summer. Emergence and reproduction occurs during this time for a number of the species that are being monitored for changes in size classes and abundance. (Those data appear later in this element.) The highest number of individuals occurred in 1986. Numbers decreased, as expected in the autumn and winter of that year. However, they never decreased to the low levels found in previous years. The next May - June (1987) numbers again increased but not to the high levels of 1986. The summer peak of 1987 was not nearly as obvious as in previous years, owing to high numbers before and after the summer of 1987. Rather than continuing to descend through December, numbers of individuals peaked again that month. It was the first December that samplers could be collected directly without having to cut through the ice. The mild winter of 1986-1987 may have contributed to the increased numbers of individuals, especially notable in samples from FEX. Numbers of individuals in the summer of 1988 were similar to those found in the summer of 1984.

Numbers of individuals were usually lower at FCD than at FEX (Fig. 4.3B). Increases in numbers during summer months at FEX was seldom matched at FCD. These differences between the two sites graphically points up the fact that it is very difficult to locate a 'true' control site for an experimental site along a river course. The unidirectional flow, coupled with feeder streams and changes in topography and base substrate alter stream characteristics sufficiently to make the researcher cognizant of the fact that changes in temporal data within a site must be considered first before changes between sites are to be compared. This is especially germane for the present long-term study. If there are definite temporal patterns for each site and an unexpected event occurs at the experimental site (FEX) when E.L.F. is in operation but the reference site (FCD) shows no change, one would suspect E.L.F. effects. Owing to downstream flow factors, any environmental factor that may imprint only on FEX has to be considered as well; for example, anthropogenic activity other than ELF activity generated near FEX that is dissipated before reaching FCD may result in the rejecting the hypothesis that there are ELF effects when, in fact that is not the case.

Variances coupled with means are relevant variables when potential effects of anthropogenic factors may be involved. Changes in coefficient of variation (C.V.) values can be useful in determining whether there are months where the variance relative to the mean is so high that 'before and after' effects may be undetectable even though the sample number may be high. In that case, it is prudent to analyze those portions of the data set where the variance to mean ratios are sufficiently low



to be confident 95% of the time of detecting a 40% difference in means between the two sites at the .05 significance level. For our sample numbers, the C.V. values have to fall below 20%.

Grand mean values for C.V. values for the structural community parameters appear in Table 4.4. Only numbers of individuals had high coefficient of variation values. For the remaining parameters, the lowest C.V. values were for samples from May through November. The highest were for winter and early spring samples. Grand mean C.V. values for May through November are presented below the grand mean values for all months.

TABLE 4.4  
Coefficient of Variation Values for Monthly Samples  
H', S, J' and No. Individuals  
July 1983 through August 1988

Statistic	Diversity	Richness	Evenness	Number Individ.
<hr/>				
1. ALL DATA				
FEX				
Grand Mean	12.86	14.42	12.10	31.39
S.D.	7.35	12.11	7.61	17.09
N = 52				
FCD				
Grand Mean	16.45	16.10	14.68	32.07
S.D.	7.78	7.81	6.63	15.96
N = 53				
<hr/>				
2. MAY THROUGH NOVEMBER DATA				
FEX				
Grand Mean	11.01	10.23	10.60	28.34
S.D.	6.46	4.36	6.32	12.19
N = 37				
FCD				
Grand Mean	13.54	14.74	11.98	30.53
S.D.	5.96	6.44	4.83	15.51
N = 37				
<hr/>				

Differences in mean values for taxon diversity, richness and numbers of individuals for FEX versus FCD appear in figures 4.4A, 4.4B, and 4.4C. Overall, FEX samples show higher diversity, taxon richness, and higher mean numbers of individuals than samples from FCD. Diversity at FCD, however, was usually higher in May, June and July each year (Figure 4.4A). Taxon richness was usually higher at FEX than at FCD (Figure 4.4B). Numbers of individuals except for May of 1984 was always higher

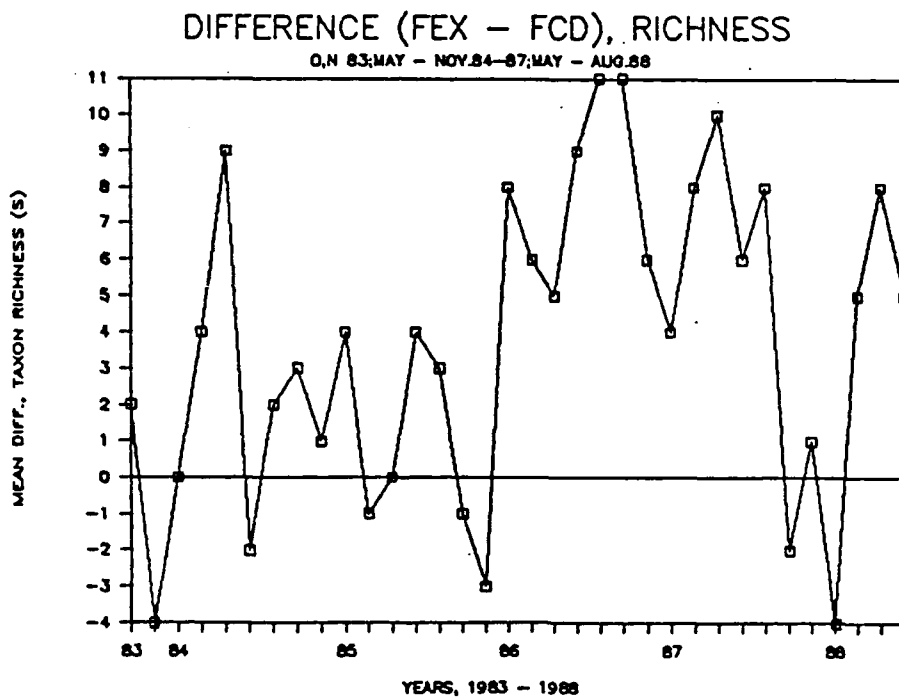
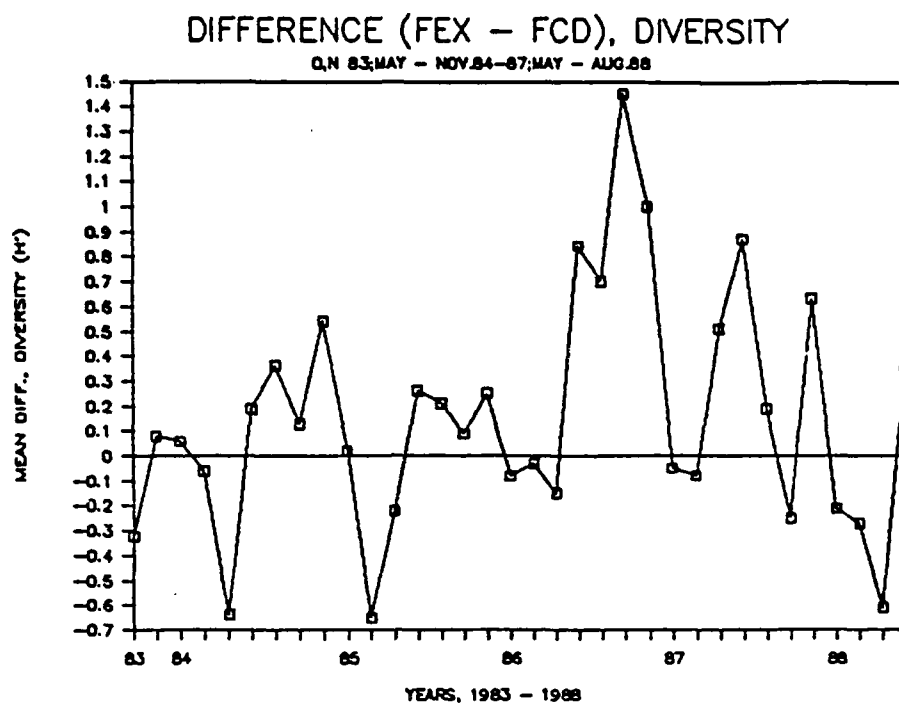


Figure 4.4A. Differences in Mean Taxon Diversity, FEX minus FCD. October, November 1983; May through November 1984 - 1987, and May through August 1988.

Figure 4.4B. Differences in Mean Taxon Richness, FEX minus FCD. October, November 1983; May through November 1984 - 1987, and May through August 1988.

FIGURE 4.4C DIFFERENCE (FEX - FCD), INDIVIDUALS

O.N 1983: MAY-NOV. 1987: MAY-AUG. 1988

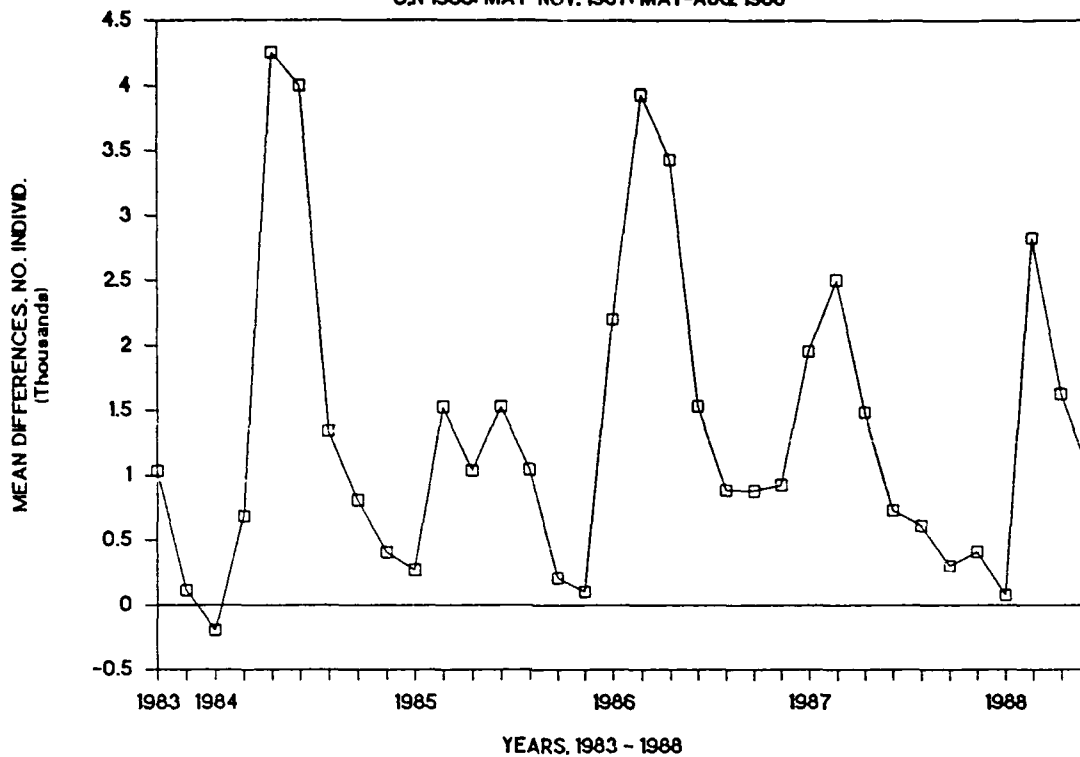


FIGURE 4.4C. Differences in Mean Numbers of Individuals, FEX minus FCD. October, November 1983; May through November 1984 - 1987; and May through August, 1988.

at FEX (Figure 4.4C). Water temperatures, treated as cumulative degree days (base = 20C), were higher from 1986 through 1988 than from 1984 through 1985 (figures 4.5A, 4.5B). Taxon diversity and richness indices remained higher at FEX over that period (figures 4.4A, 4.4B).

In July of 1986 ELF was activated at FEX. The intensity and duration was very low in 1986 and 1987, but higher in 1988. Had there been no clear differences in precipitation and temperature in 1986 through 1988 as compared to previous years, ELF activation could have been implicated as positively affecting diversity and richness values. Faster accumulation of water temperature degree days from April through October of 1986, 1987 and 1988 as compared with previous years (figures 4.5A, 4.5B) may affect taxon diversity and richness values more at the FEX site which is closer to the headwaters of the Ford River. If 1989 and 1990 summer temperatures and rainfall patterns are similar to those in 1984 and 1985, we expect that the differences in diversity and richness values will be similar to those found between FEX and FCD in 1984 and 1985. If differences remain high in spite of more mild weather patterns in 1989 and 1990, ELF activation may be suspected as affecting some structural community parameters for the benthic insects.

As more data accumulate after full power of ELF, Before and After Control and Impact (BACI) analyses will be done (Stewart-Oaten et al. 1986). As for now, the environmental 'noise' appears to override any possible effects of ELF.

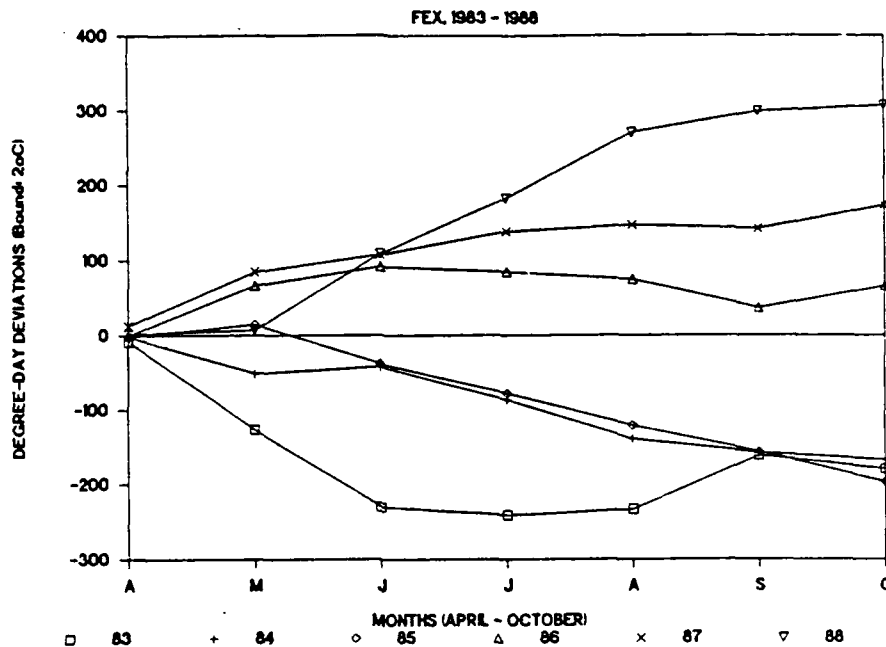
### Functional Community Indices

#### Biomass and Functional Feeding Groups:

Seasonal trends for total insect biomass at FEX and FCD from June 1983 through August 1988 appear in Figure 4.6A. Companion coefficient of variation values appear in Figure 4.6B. From the spring and summer of 1986 through the spring of 1987 the total biomass at FEX remained very high. Coefficient of variation values were low during that time (except in the early spring) as well. The high biomass is probably related to the high early spring water temperatures in 1986 and to the mild winter that followed. In the fall of 1987, biomass at both sites again decreased as in the fall of 1983, 1984 and 1985. However, the decrease did not decrease as far as during the fall and winter months of 1983, 1984 and 1985.

Coefficient of variation values were the highest in the spring months when total biomass was usually lowest. Changes in species assemblages and fast growth rates can occur during spring months. For example, five of the seven species selected for intensive study have fast growth rates in the spring and early summer months. It is possible that higher coefficient of

# DEVIATIONS IN MEAN VALUES, DEGREE-DAYS



# DEVIATIONS IN MEAN VALUES, DEGREE-DAYS

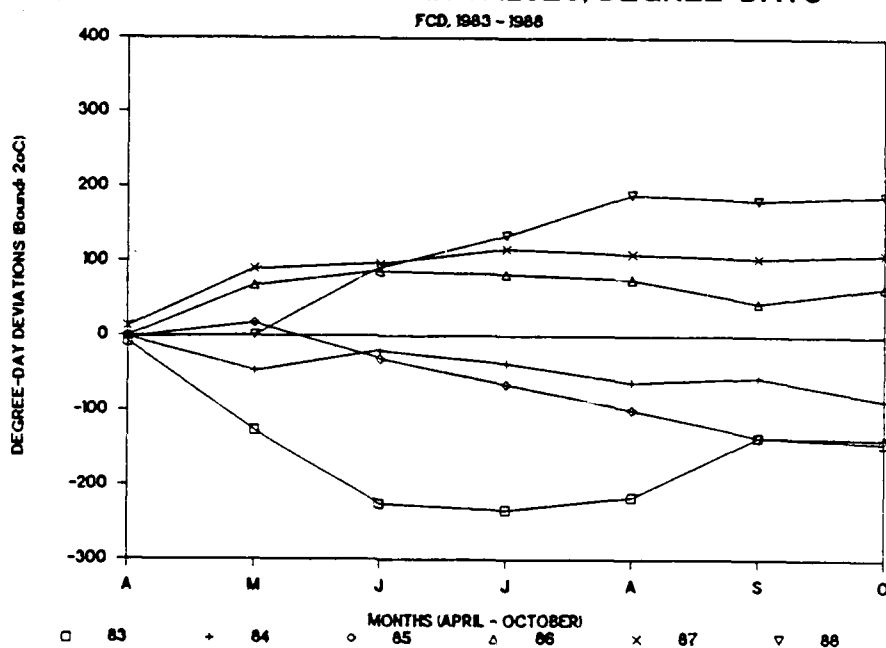


Figure 4.5A. Deviations from Cumulative Mean Degree-Day Values at FEX. April through October, 1983 through 1988. (Threshold value: 2 oC.)

Figure 4.5B. Deviations from Cumulative Mean Degree-Day Values at FEX. April through October, 1983 through 1988. (Threshold value: 2 oC.)

FIGURE 4.6A TOTAL BIOMASS, FEX AND FCD

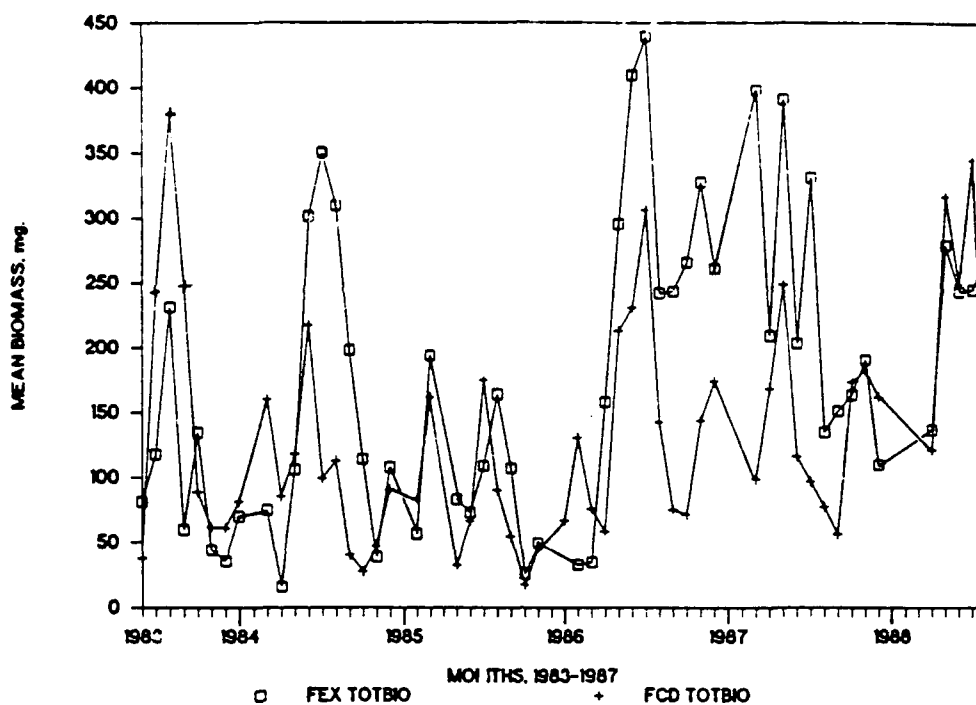


FIGURE 4.6B COEFFICIENT OF VARIATION

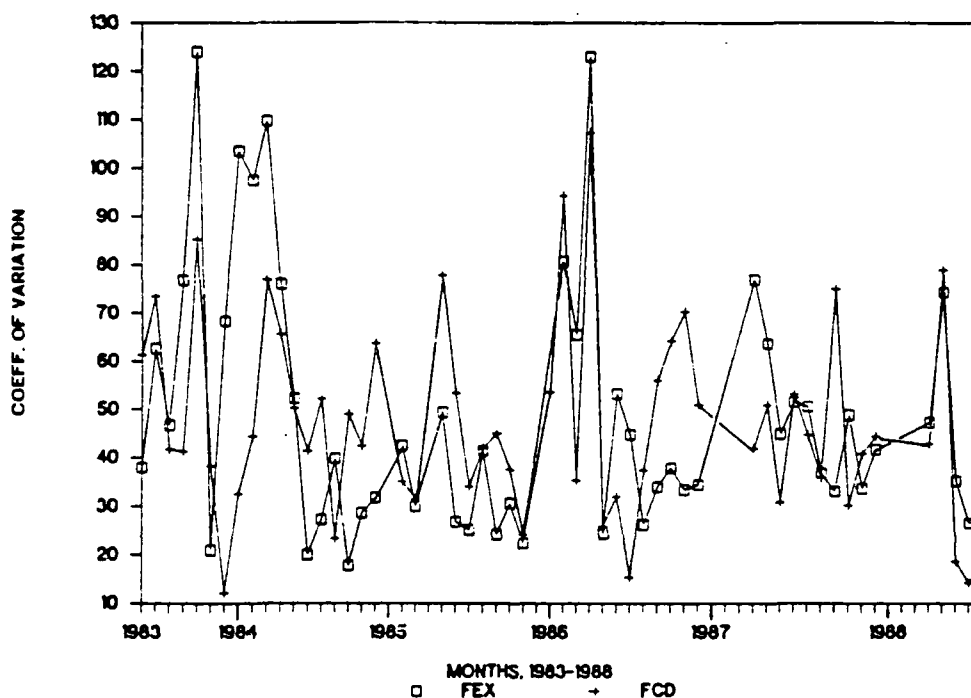


Figure 4.6A. Changes in Insect Mean Total Biomass (mg.) at FEX (squares) and FCD (pluses) from June, 1983 to August, 1988.

Figure 4.6B. Changes in Coefficient of Variation (C.V.) Values at FEX (squares) and FCD (pluses) from June, 1983 to August, 1988.

variation values for the insect biomass reflect periods of rapid growth and transition to adult areal stages.

Correlation coefficients for physical parameters and biotic parameters over time were analyzed to determine relationships among them. Water temperatures, discharge levels, and underwater solar radiation showed the most significant correlations with respect to biotic variables. From June 1983 (when final sites for ELF were selected) through August of 1988, water temperatures were correlated with ln values for total insect biomass and diatom density, Table 4.5. Data come from studies conducted throughout each year, and thus, include late fall and winter months.

TABLE 4.5

Correlation Coefficients Total Insect Biomass, Diatom Density and Water Temperatures, FEX and FCD Combined  
June 1983 through August 1988

	Ln Periphyton Density	Ln Insect Biomass	Water Temp.
Ln Periphyton	1.000		
Ln Insect Bio.	.621	1.000	
Water Temp.	.664	.496	1.000
Critical Value (1-tail, .05) = + or - .226			
Critical Value (2-tail, .05) = + or - .168			

Figure 4.7 shows mean values over time for those parameters. Regression coefficients were high in 1983 through the summer of 1986 (See 1987 Annual Report, p. 153). After the summer of 1986, the values dropped. Figure 4.7 shows that from the summer of 1986 onward, periphyton density and insect biomass peak values were higher than in previous years. Those two parameters did not relate to each other as well as in past years. Table 4.6 and figures 4.8A, 4.8B and 4.8C show regression values and plots of those parameters and water temperatures from 1983 through August 1988.

TABLE 4.6

Regression Coefficients for Mean Insect Biomass, Diatom Density and Water Temperature, June 1983 - August 1988

Comparisons	r <sup>2</sup>	p value
Ln Diatom Density vs. Ln Insect Biomass	.385	<.00001
Water Temperature vs. Ln Insect Biomass	.246	.0002
Water Temperature vs. Ln Diatom Density	.464	<.00001

# INSECTS, PERIPHYTON, AND WATER TEMP.

FEX AND FCD COMBINED

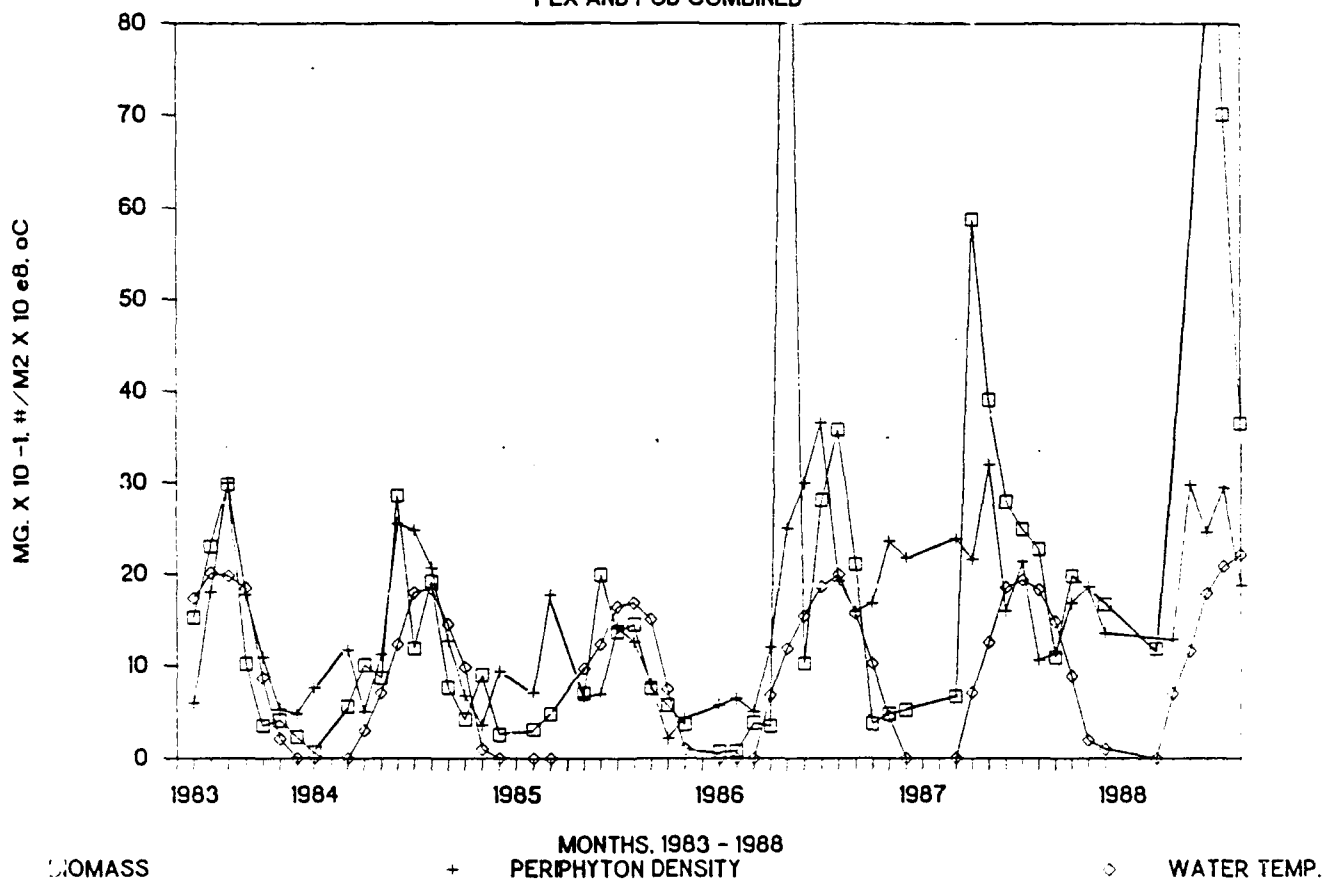


Figure 4.7. Changes in Insect Mean Total Biomass (mg./sample X 10<sup>-1</sup>, Diatom Density (numbers per square meter X 10<sup>e8</sup>) and Water Temperature (° Centigrade) for FEX and FCD Combined. June 1983 to August 1988.



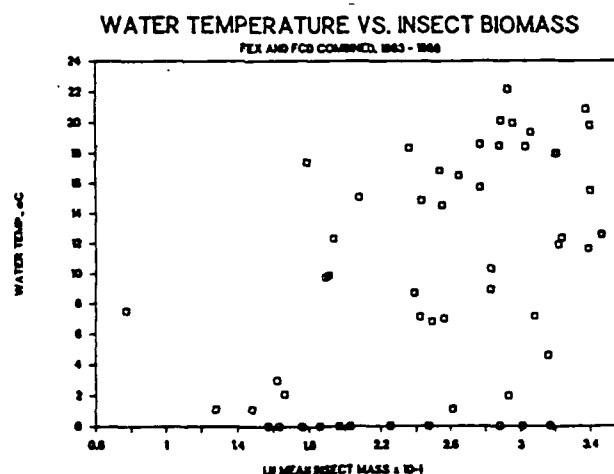
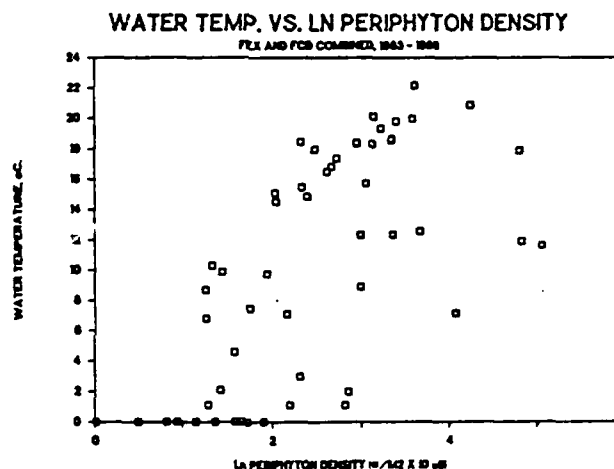
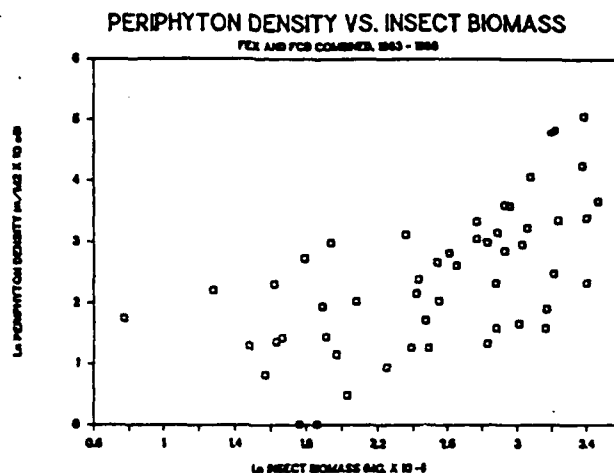


Figure 4.8A. Relationship of Ln Periphyton Density (No./M2 X 10<sup>6</sup>) at Combined Sites and Ln Total Insect Biomass (mg.), June 1983 to August 1988. R<sup>2</sup> = 0.39, T = 5.67, p < 0.00001.

Figure 4.8B. Relationship of Water Temperature (°C Centigrade) at Combined Sites and Ln Total Insect Biomass (mg.), June 1983 to August 1988. R<sup>2</sup> = 0.25, T = 4.08, p = .0002.

Figure 4.8C. Relationship of Water Temperature (°C Centigrade) at Combined Sites and Ln Diatom Density (No./M2 X 10<sup>6</sup>) June 1983 to August 1988. R<sup>2</sup> = 0.44, T = 6.35, p < 0.00001.

Data for physical variables other than water temperatures are available from spring through fall each year (usually April through October). Those include discharge, above-water solar and underwater solar radiation, rainfall, and air temperatures. Solar radiation below the water and water discharge showed high correlation coefficients with respect to insect biomass and periphyton density. Correlation coefficients for diatom density, total insect biomass, water temperature, discharge, and underwater solar radiation for spring through fall each year appear in Table 4.7.

TABLE 4.7

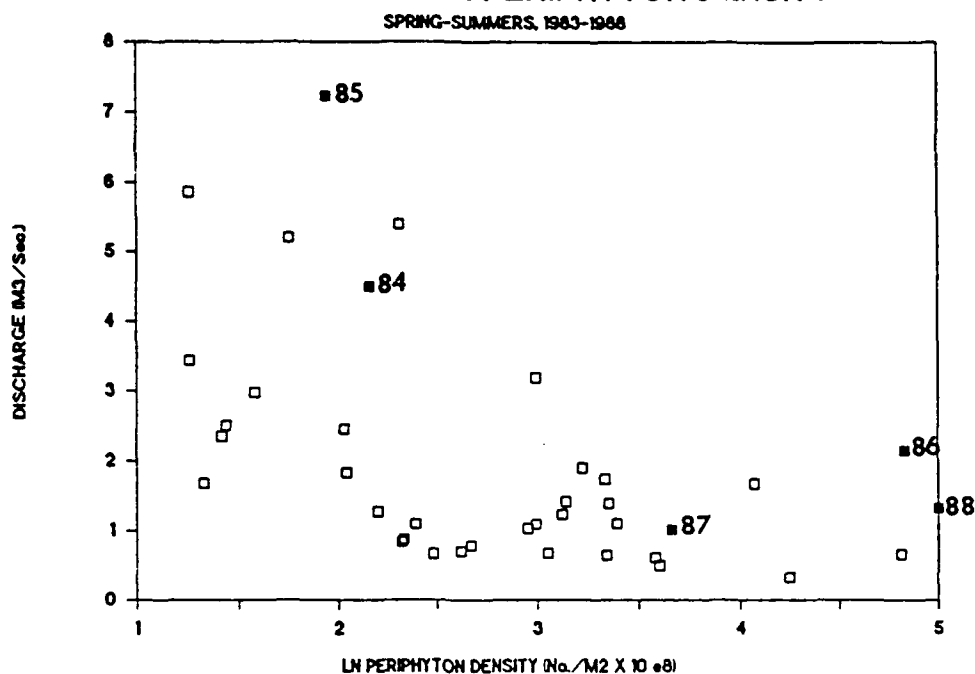
Correlation Coefficients for Biological and Physical Parameters  
From April or May through September or October each Year\*,  
1983 - 1988

	Ln Peri. Density	Ln Insect Biomass	Water Temp.	Dis- charge	Solar Below
Ln Peri.Density	1.000				
Ln Insect Bio.	.59	1.000			
Water Temp.	.19	.40	1.000		
Discharge	-.39	-.73	-.67	1.00	
Solar (below)	.65	.59	.23	-.48	1.000

Critical value (1-tail, .05) = + or - .27 \*38 sample dates  
Critical value (2-tail, .05) = + or - .32

When those months are considered, water temperatures are not significantly correlated with ln periphyton density. However, discharge (M<sup>3</sup>/sec.) and solar underwater radiation (P.A.R.) variables are significantly correlated with ln periphyton density. Regression plots of discharge (Figure 4.9A) and underwater solar radiation (Figure 4.9B) against ln periphyton density show that discharge is negatively correlated and underwater solar radiation is positively correlated with ln periphyton density. Underwater solar radiation accounts for much more of the variance of periphyton density (42%) than does discharge (16%). There appears to be a discharge threshold that periphyton can withstand without being eroded from slides. The most obvious effect of high or low discharge on periphyton density occurs during late spring months when reduced leaf canopy allows sun penetration, and thereby enhanced periphyton growth. May periods from 1986 through 1988 show lower discharge values (maximum discharge 2.15 cubic m per sec.) than for prior May periods. In 1984 and 1985, May discharge averaged 4.50 and 7.23 cubic m per sec., respectively. In those cases, periphyton densities were very low. Figure 4.9A denoting May periods is used to suggest that there is a discharge threshold, below which periphyton can accumulate during normal maximum growth periods. The relatively low regression coefficient for discharge against periphyton density may be caused by a discharge threshold.

# DISCHARGE VS. Ln PERIPHYTON DENSITY



# DISCHARGE VS. Ln INSECT BIOMASS

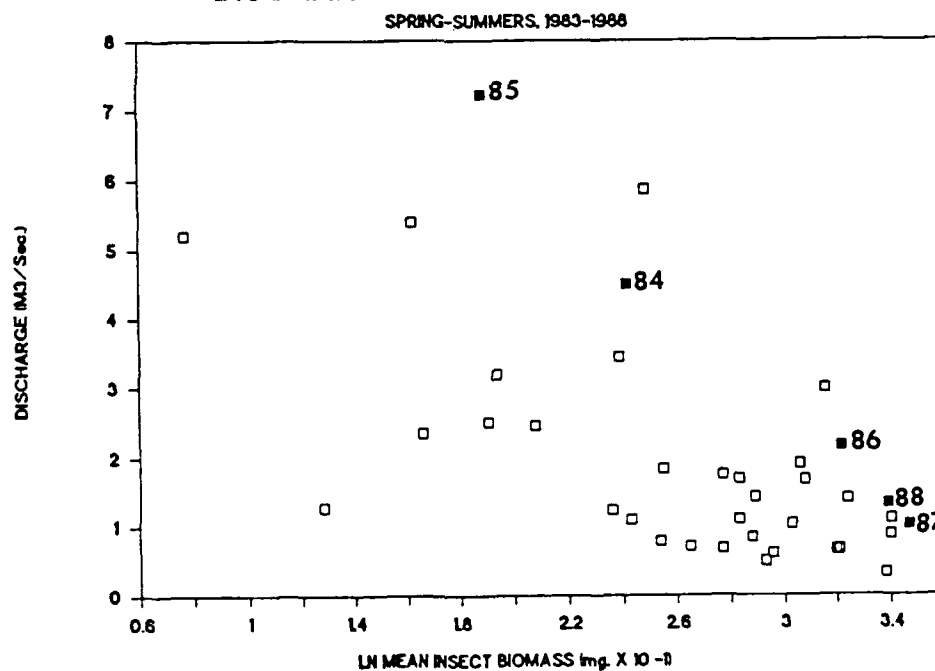


Figure 4.9A. Relationship between Discharge (M<sup>3</sup>/Sec.) at Combined Sites and Ln Periphyton Density (No/M<sup>2</sup> X 10<sup>8</sup>). Late Spring through Summer each year, 1983 - 1988. Filled squares: May each year.  $R^2 = 0.16$ ,  $T = -2.18$ ,  $p = 0.038$ .

Figure 4.9B. Relationship between Underwater Solar Radiation (P.A.R.) and Ln Periphyton Density (No/M<sup>2</sup> x 10<sup>8</sup>). Late Spring through Summer each year, 1983 - 1988. Filled squares: May each year.  $R^2 = 0.42$ ,  $T = 4.38$ ,  $p = 0.0002$ .

The higher  $r^2$  value for underwater solar radiation versus periphyton density may be related to an absence of solar radiation thresholds, Figure 4.9B. Each May (for which there solar radiation data) is represented by black squares for comparison with May periods in other figures.

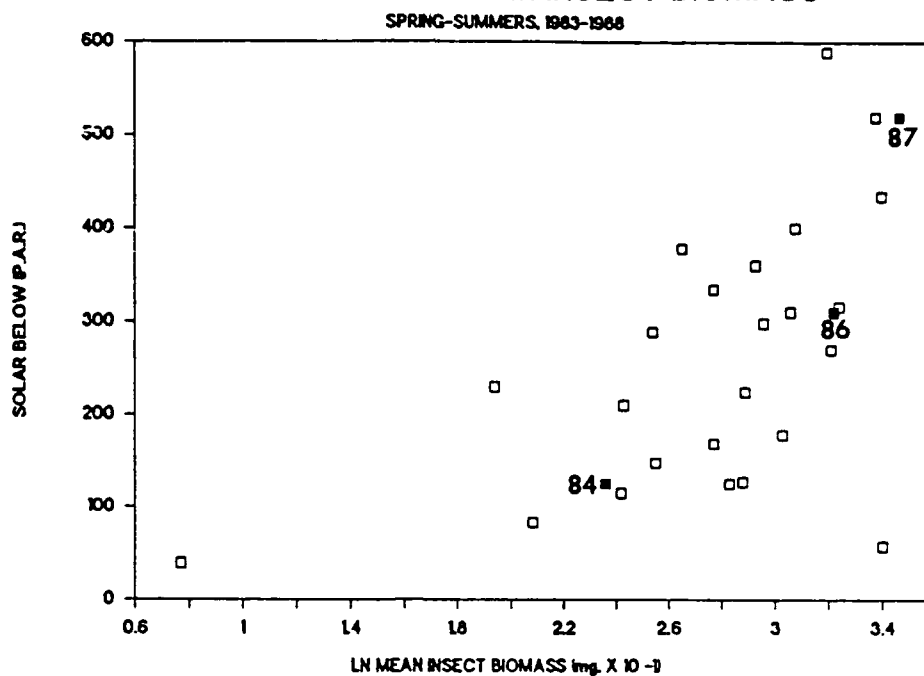
Both discharge and underwater solar radiation values were highly correlated with total mean insect biomass (Figure 4.10A and Figure 4.10B, respectively). Over 50% of the variation in  $\ln$  insect biomass is accounted for by discharge alone; underwater solar radiation accounts for 35% of  $\ln$  insect biomass variation. If only May periods of each year are considered for discharge versus insect biomass, they fall very close along the regression line (Figure 4.10A). If May discharge values are known, one could rather confidently predict  $\ln$  mean insect biomass for FEX and FCD taken together. Thus, a discharge threshold for insect biomass is not apparent, but was apparent for diatom density. For the most part, insect biomass was high when discharge values were 2 m<sup>3</sup>/sec. or less. This was usually the case during the summer and early fall months (see also Figure 4.7).

Total biomass values were separated into functional feeding groups (F.F.G., after Merritt and Cummins, 1984) for site comparisons. Total insect biomass incorporates many taxa with differing modes of feeding; thus, biomass values for F.F.G. should have lower variances over time. ELF effects may be more detectable if F.F.G. rather than total insect biomass is used.

Predators contributed more to total biomass than the other three F.F.G., Shredders, Collector-Filter Feeders and Collector-Gatherers (figures 4.11A, 4.11B, 4.12A, 4.12B). One major predator, the dragonfly Ophiogomphus colubrinus contributed the most biomass to that functional feeding group (F.F.G.). It is this predator that we are monitoring for possible changes in movement patterns as a function of ELF (Element 5). Three F.F.G. showed seasonal patterns similar to the total biomass patterns: Collector-filter feeders, collector-gatherers (Figure 4.12A, B) and predators (Figure 4.11A). Shredders had many peaks and those biomass peaks did not correspond to peaks for the three other F.F.G. Shredder biomass had higher peaks during the fall and winter months (Figure 4.11B). That is to be expected, as shredders should be more common during and after autumnal leaf fall.

Collector-filter feeders and collector-gatherers were the functional feeding groups (F.F.G.) that inflated total biomass at FEX in 1986-1987. Warmer weather and fewer days of snow cover in the river appeared to positively affect growth and/or survival for members in these groups. The major increase in biomass for collector-filter feeders were hydropsychid larvae and they were most abundant at FEX. There is more cobble and less sand at FEX. It is possible that the FEX site is more conducive to collector-filter feeders and collector-gatherers under mild winter conditions than the FCD site.

# SOLAR BELOW VS. Ln INSECT BIOMASS



# SOLAR BELOW VS. Ln PERIPHYTON DENSITY

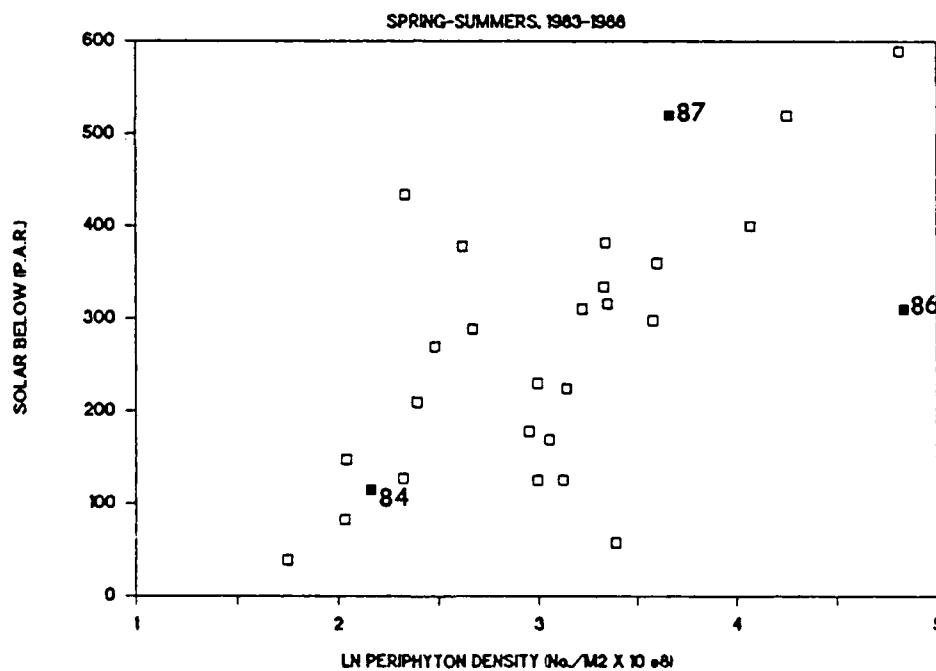


Figure 4.10A. Relationship between Discharge ( $M^3/Sec.$ ) at Combined Sites and Ln Total Insect Biomass ( $mg. \times 10^{-1}$ ). Late Spring through Summer each year (Filled Squares: May) from 1983 to 1988.  $R^2 = 0.54$ ,  $T = -5.52$ ,  $p = 0.00001$ .

Figure 4.10B. Relationship between Underwater Solar Radiation (P.A.R.) and Ln Total Insect Biomass ( $mg. \times 10^{-1}$ ). Late Spring through Summer each year (Filled Squares: May) from 1983 - 1988.  $R^2 = 0.35$ ,  $T = 3.75$ ,  $p = 0.0009$ .

FIGURE 4.11A PREDATOR BIOMASS

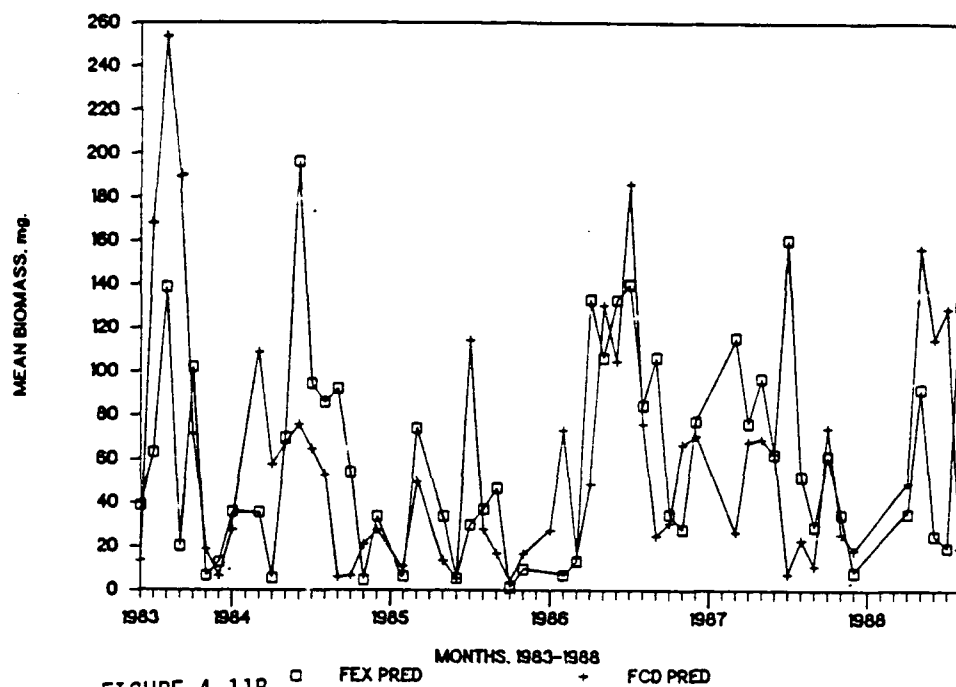


FIGURE 4.11B

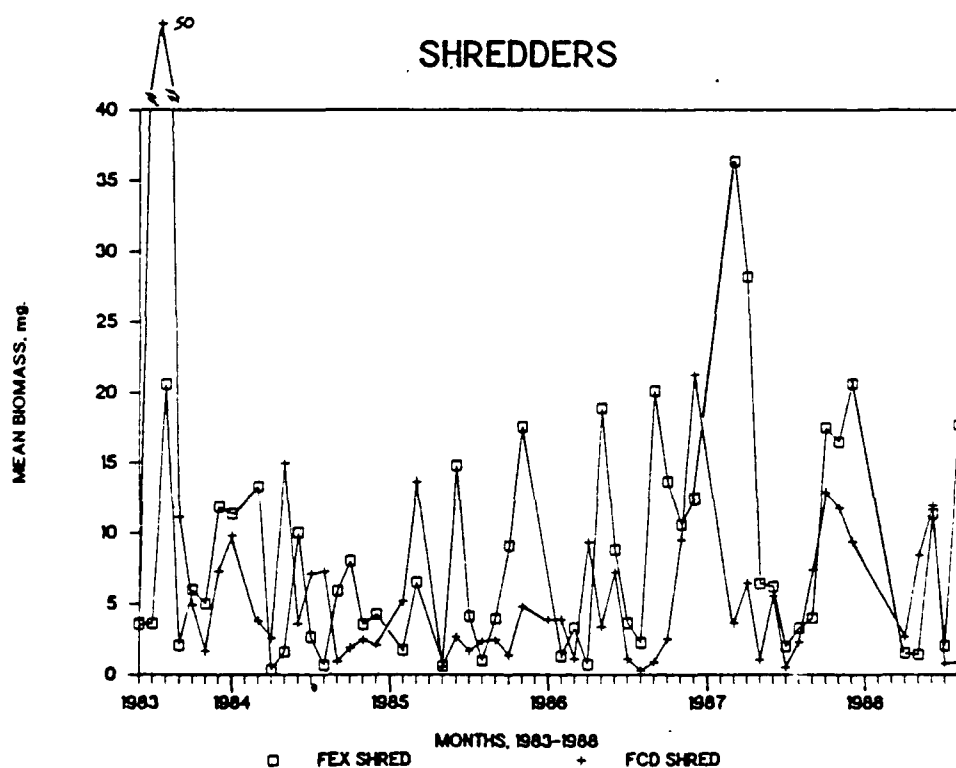


Figure 4.11A. Changes in Mean Predator Biomass (mg.) per sample at FEX (squares) and FCD (pluses). June 1983-August 1988.  
 Figure 4.11B. Changes in Mean Shredder Biomass (mg.) per sample at FEX (squares) and FCD (pluses). June 1983-August 1988.

FIGURE 4.12A COLLECTOR-FILTER FEEDERS

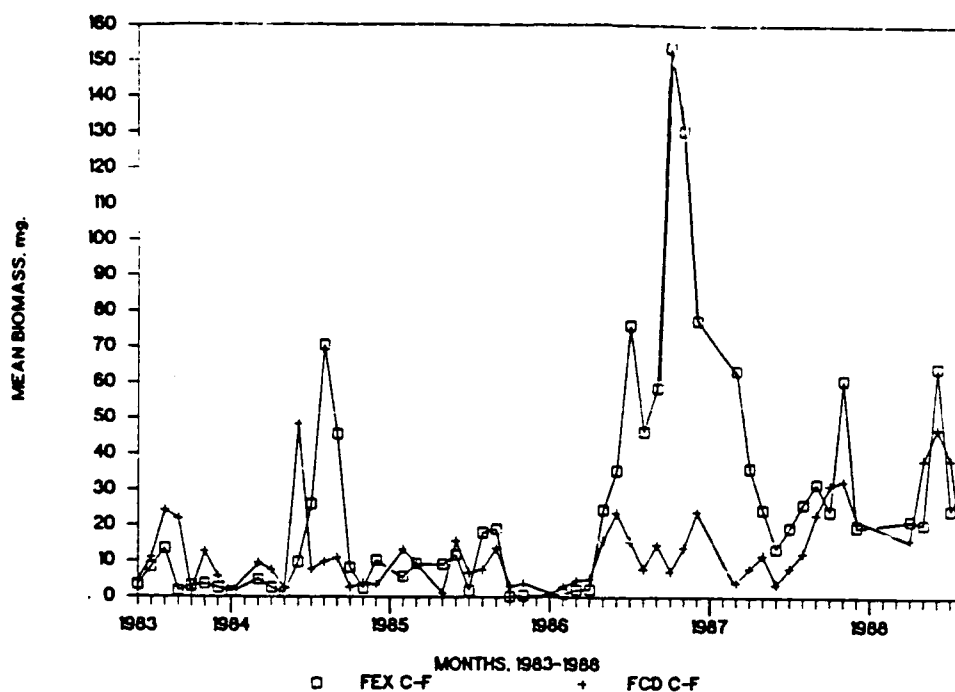


FIGURE 4.12B COLLECTOR-GATHERERS

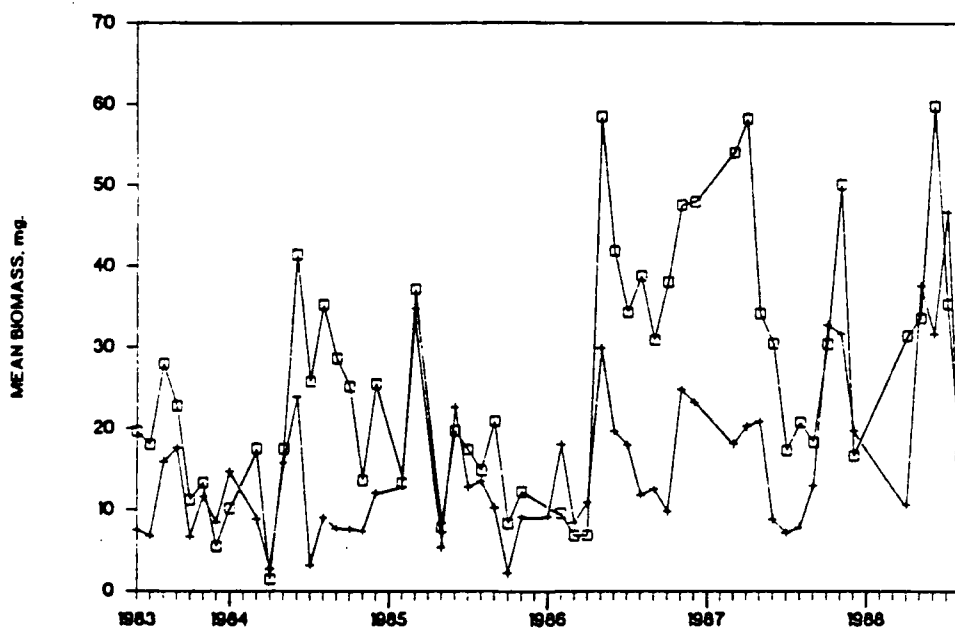


Figure 4.12A. Changes in Mean Collector-Filter Feeder Biomass (mg.) per sample at FEX (squares) and FCD (pluses). June 1983 - August 1988.

Figure 4.12B. Changes in Mean Collector-Gatherer Biomass (mg.) per sample at FEX (squares) and FCD (pluses). June 1983 - August 1988.

Correlation coefficients for F.F.G. and total insect biomass within sites appear in Table 4.8A. Table 4.8B shows between site C.C. values. Table abbreviations are:

TB = Total Biomass                      CF = Collector-Filterers  
CG = Collector-Gatherers              S = Shredders  
P = Predators

TABLE 4.8A

Correlation Coefficients for Insect Functional Feeding Groups Related to Total Insect Biomass at FEX and FCD

	TB	F CF	E CG	X CG	S		TB	F CF	C CG	D CG	S
TB	1.00						1.00				
CF	.58	1.00					.64	1.00			
CG	.70	.62	1.00				.64	.71	1.00		
S	.23	.32	.46	1.00			.47	.20	.09	1.00	
P	.74	.14	.37	.17			.86	.41	.37	.58	

Critical value (1-tailed, .05) = + or - .23

Critical value (2-tailed, .05) = = or - .27

TABLE 4.8B

Correlation Coefficients Between FEX and FCD for Insect Total Biomass and Functional Feeding Groups

	TB	F CF	E CG	X CG	S	P
F						
C						
D						
TB	.51					
CF	.33	.22				
CG	.36	.24	.60			
S	.02	-.03	.08	.16		
P	.31	.04	.31	-.02	.31	

Critical Value (1-tailed, .05) = + or - .23

Critical Value (2-tailed, .05) = - or - .27

In general, within site correlation coefficients were higher (Table 4.8A) than between site values (Table 4.8B). Predators, shredders and collector-filter feeders were more highly correlated with total biomass at FCD than were those groups at FEX.

Only total insect biomass and biomass of collector-gatherers were highly correlated between sites (C.C. = 0.51, 0.60, respectively, Table 4.8B). Most of the taxa monitored for changes in growth and numbers are collector-gatherers. As this functional feeding group shows the most similarity between



sites, it is appropriate that those taxa are being used to determine if ELF may have an effect on growth or on changes in numbers over time.

Differences between mean values for total insect biomass and for F.F.G. at FEX versus FCD were computed to see whether differences in patterns would emerge between the two sites (Figure 4.13) after ELF was activated. December through April data were excluded, as C.V. values are high during those times (see Figure 4.6B). In 1983, 1984 and 1985 there were short periods when total insect biomass was higher at FCD than at FEX. From 1986 through September of 1987 total insect biomass was always higher at FEX than at FCD. In May through July of 1987 total insect biomass was higher at FCD. Had we not the 1987 data, we would wonder whether ELF increased total insect biomass, especially if we chose not to incorporate natural environmental differences between the two sites in our analyses. In essence, we did not observe the usual autumn switch in total biomass from FEX to FCD. In other years, insect biomass decreased at both sites (Figure 4.6A). Hydropsychid caddisflies were the major contributors of biomass at FEX in the fall of 1986. The hot, dry summer and fall of 1986 (Figure 4.5A, B), coupled with more cobble at the upstream FEX site is probably the causative agent for differences between FEX and FCD rather than activation of ELF. After the 1989 field season, environmental differences between the two sites will be used as covariates to take those differences into account. We will perform B.A.C.I. analyses to see if there are significant differences before versus after activation of ELF.

Deviations from mean values of collector-gatherer, shredder, collector-filter feeder and predator biomass appear in figures 4.14A and 4.14B. All except shredders had temporal patterns similar to those for total insect biomass during the summer, fall and winter of 1986.

#### Changes in Mean Dry Weights per Individual and Numbers of Individuals

Numerical abundances, total insect biomass values and functional feeding group biomass values are "coarse-grained" parameters, and as such, they usually have high variances. A more "fine-grained" analysis was done -- an analysis of temporal changes in mean dry weight per individual values (MDW/IND) for insects that met the following criteria: 1) high numerical abundance at both sites, 2) univoltine life history (minimizing problems with overlapping generations), and 3) the sum of taxa chosen being members of differing functional feeding groups, if possible. Life cycle patterns, inferred from mean size class changes for each taxa, are described below.

a. Chironomidae. The high numbers of individuals (often 500 to 2000 per replicate) and the time necessary to identify chironomids even to generic level, forced us to group the family

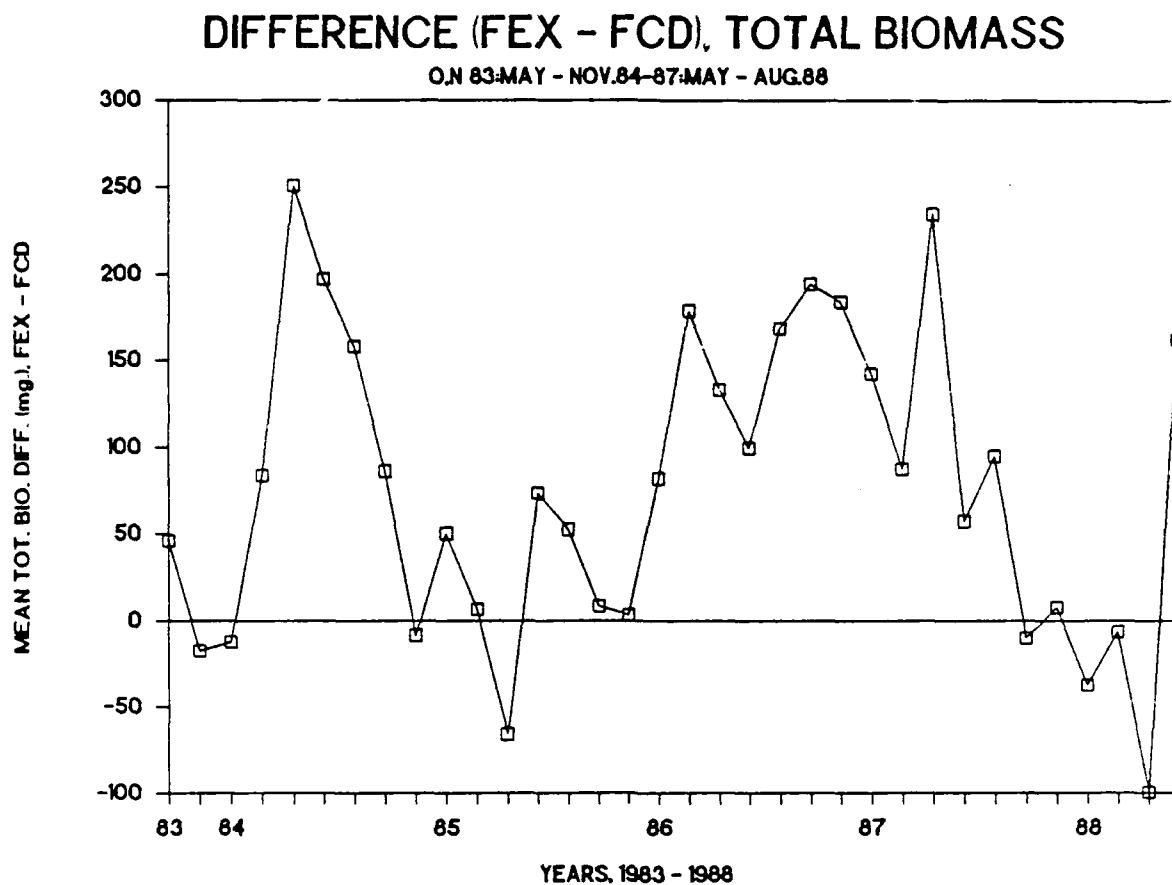


Figure 4.13. Differences in Mean Total Biomass, FEX minus FCD. October, November, 1983; May through November 1984 - 1987; May through August 1988.

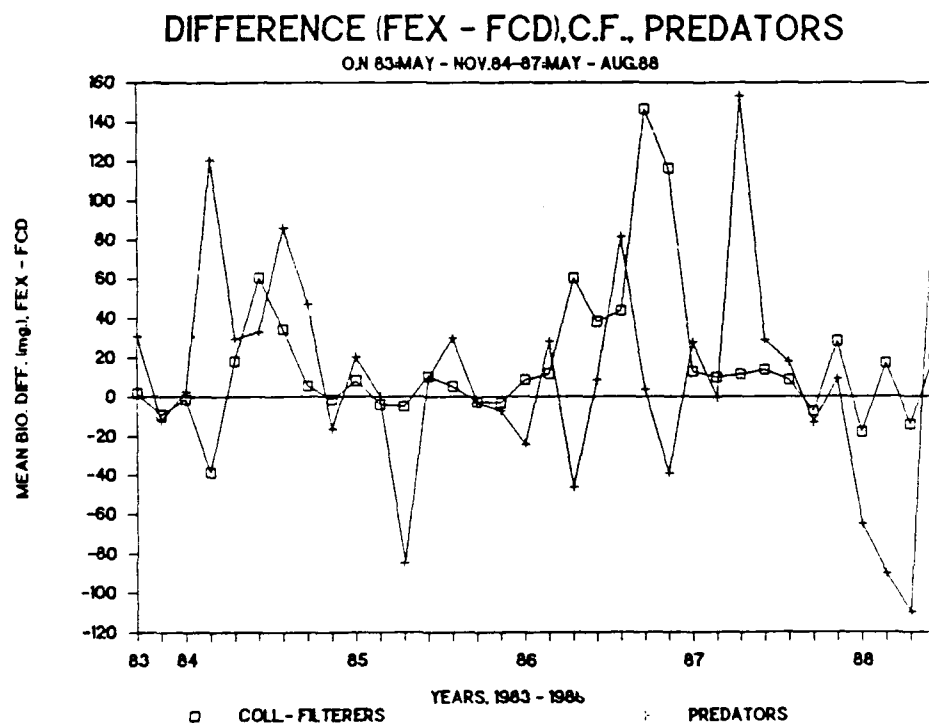
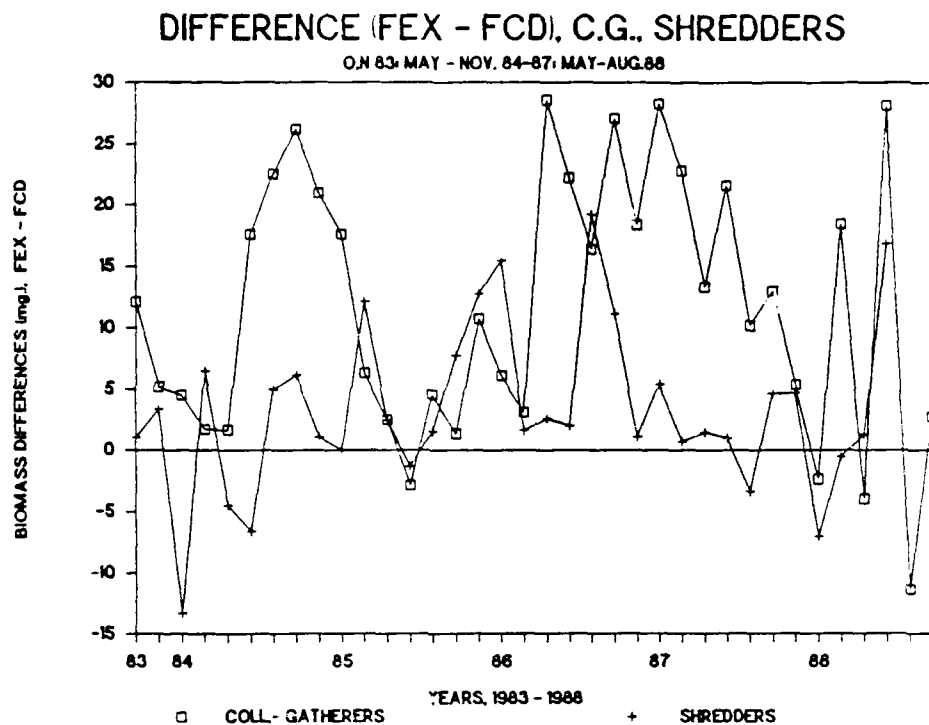


Figure 4.14A. Differences in Mean Collector-Gatherer Biomass and Shredder Biomass, FEX minus FCD. October, November, 1983; May through November 1984 - 1987; May through August 1988.

Figure 4.14B. Differences in Mean Collector-Filter Feeder biomass and Predator Biomass, FEX minus FCD. October, November, 1983; May through November 1984 - 1987; May through August 1988.

as one unit. This problem obviously confounds results, owing to differing life histories within the group. Only trends can be followed. Figure 4.15 shows that, in spite of the fact that we analyzed an entire family, a trend emerged. Small size classes occurred during the fall (September through November), and large sized individuals were found in May and June. Large mean dry weights per individual began occurring in May of 1987 at FEX. The following summer, large individuals were again found at that site. In order to determine whether one or a few large-sized species increased in abundances, samples would have to be studied in detail. If future funds and time permit, this can be done.

b. Paraleptophlebia mollis (Eaton). A very distinctive size-class pattern emerges for this mayfly collector-gatherer (Fig.4.16). It is univoltine, with its emergence being between late May and June. Numbers of individuals for this species were highest in August when the MDW/IND values are low. Apparently, eggs hatch slowly over the summer, as no mature nymphs were taken after June. Also, nymphs remained small throughout the winter and early spring. In the fall of 1986 and spring of 1987 strong growth spurts appeared, unlike previous years over those seasons. The mild winter and spring may have triggered early development for some individuals at FEX and FCD. Accelerated growth appears to usually occur over a one to two-month period in the late spring. This species has the most consistent MDW/IND seasonal patterns of all the species we are following. It has a very low growth rate for most of the year and then increases in size quickly in May and June prior to final molt. MDW/IND values for this species were plotted according to cumulative degree-days for each year (figures 4.17A, 4.17B). By using degree-days, rather than chronological time, much more information emerges. Maximum growth appears to occur after accumulation of fewer degree-days at FEX than at FCD. By using degree day techniques, we can graphically see years when peak growths were missed in collections; 1987 was missed at FEX and 1984 was missed at FCD. Further, degree day values are more accurate than chronological time for predicting emergences for this species. If ELF seriously affects numerical abundance, seasonal growth patterns, and/or emergence patterns of this species, we should be able to detect them more easily using degree-day data.

c. Ephemerella invaria (Walker) and Ephemerella subvaria McDunnough. There are distinctive size class patterns for each species (Figure 4.18A and 4.18B). Ephemerella invaria is most abundant in the early fall when its MDW/IND value is low. It appears to be univoltine, with its major emergence being in late spring. A comparison with data for this species from Element 6 (leaf processing) shows that the size classes are similar, an expected result.

Ephemerella subvaria's growth as inferred from size class data, occurs from October through late spring. Emergences may

FIGURE 4.15

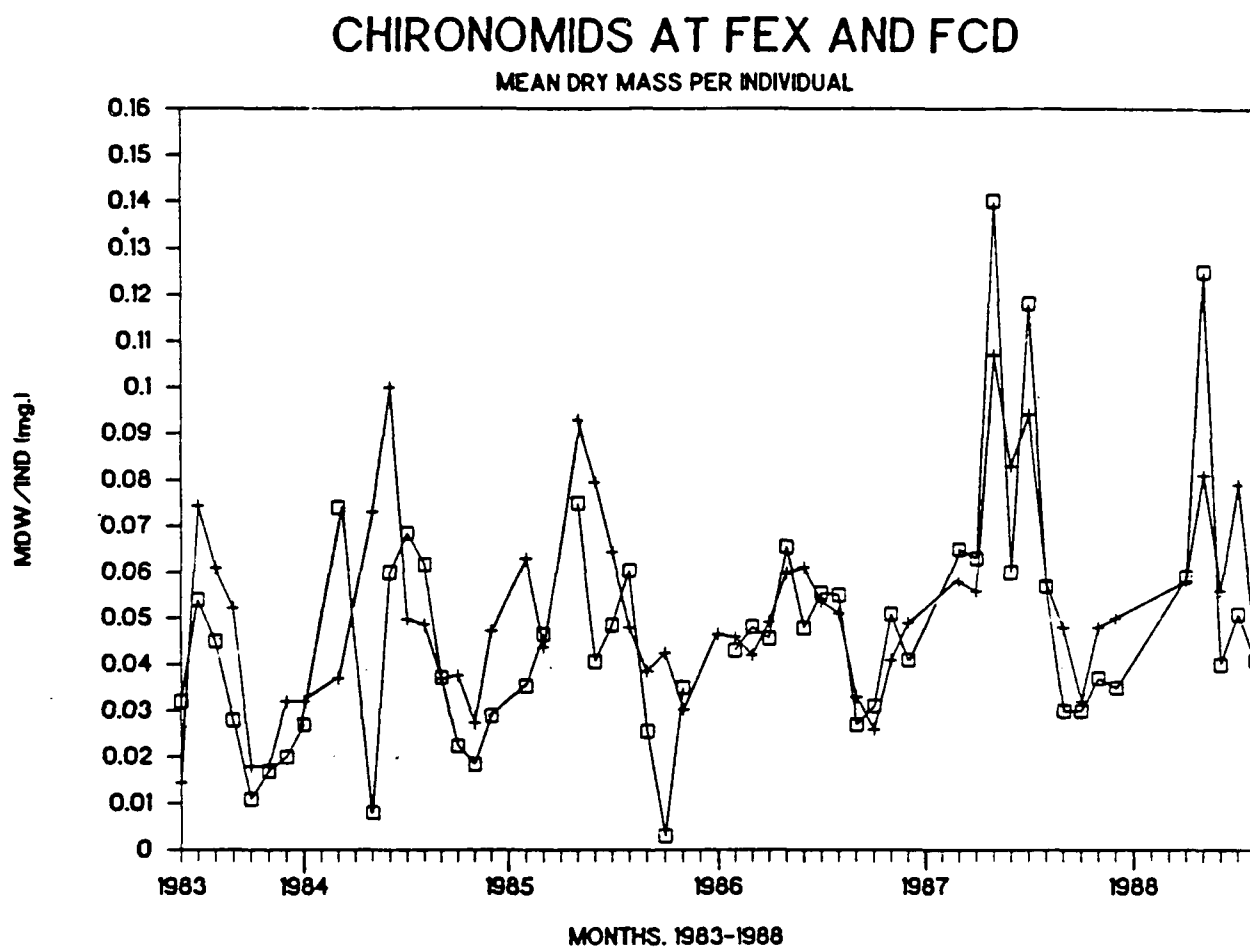


Figure 4.15. Mean Dry Weight per Individual (MDW/IND) for Chironomidae at FEX (squares) and FCD (pluses) from June, 1983 to August 1988.

FIGURE 4.16

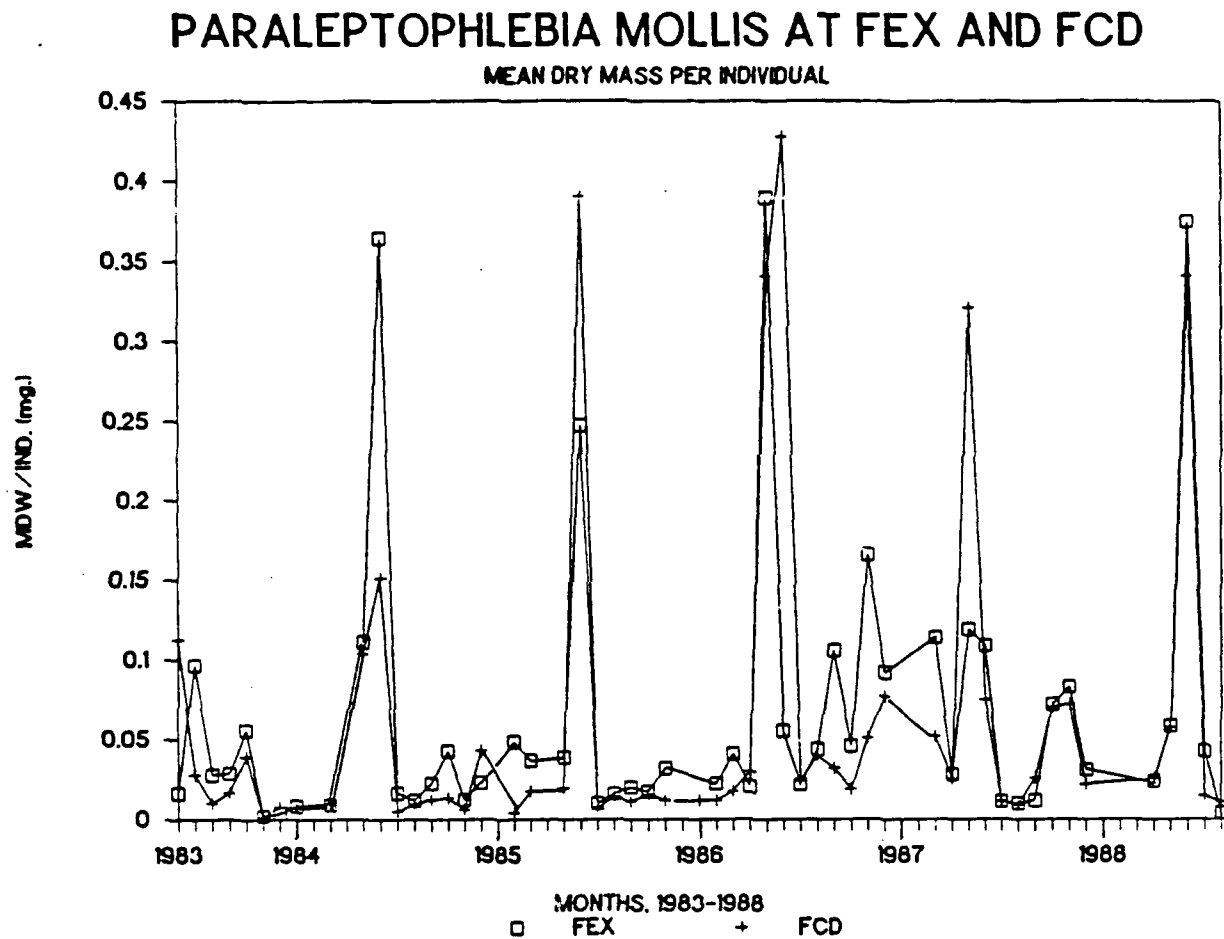


Figure 4.16. Mean Dry Weight per Individual (MDW/IND) for Paraleptophlebia mollis at FEX (squares) and FCD from June, 1983 to August 1988.

FIGURE 4.17A

A.

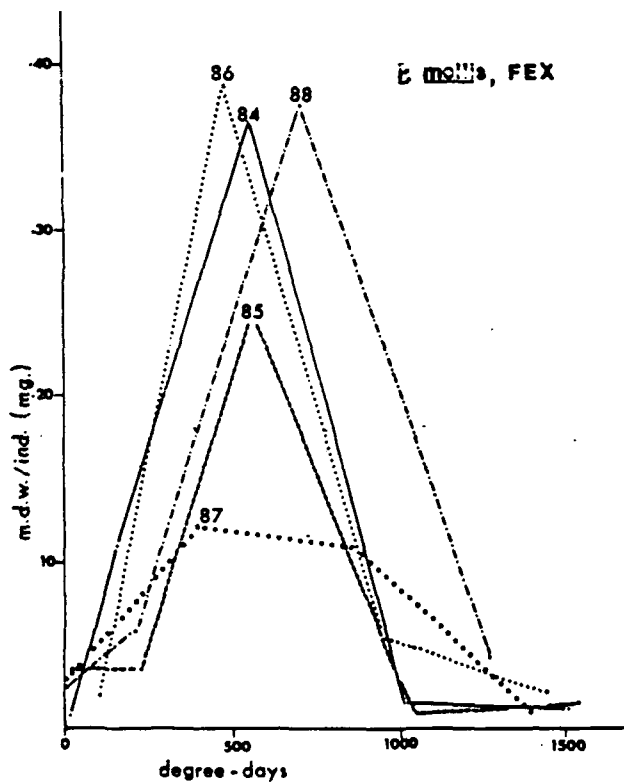


FIGURE 4.17B

B.

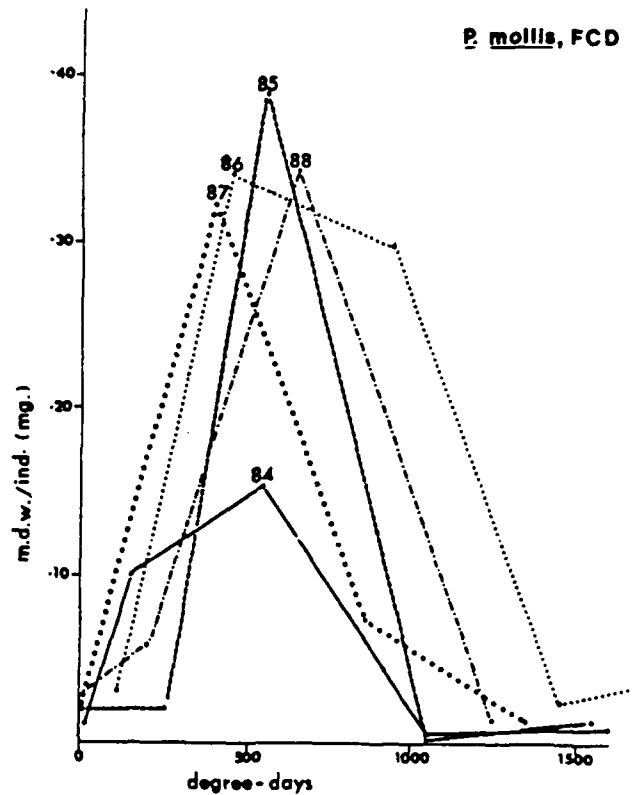


Figure 4.17A. Mean Dry Weight per Individual (MDW/IND) against Cumulative Degree Days (threshold = 2 oC). *Paraleptophlebia mollis* at FEX. Springs and early Summers of 1984 - 1988.  
Figure 4.17B. Mean Dry Weight per Individual (MDW/IND) against Cumulative Degree Days (threshold = 2 oC). *Paraleptophlebia mollis* at FCD. springs and early Summers of 1984 - 1988.

FIGURE 4.18A

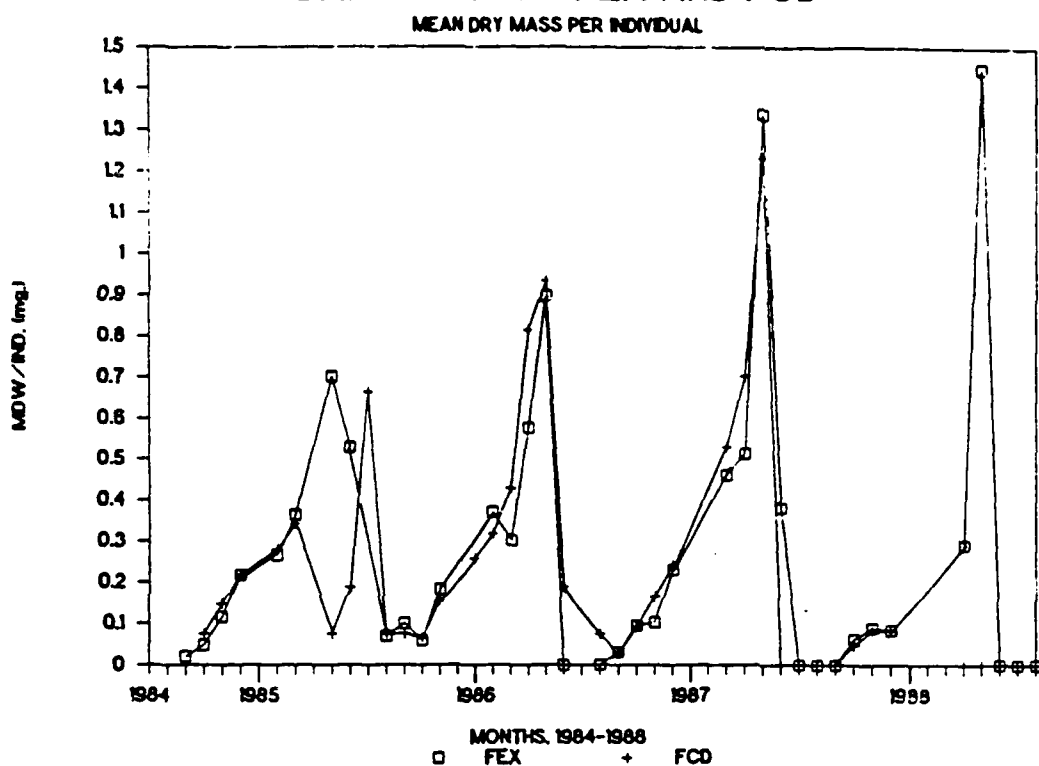
**E. INVARIA AND FEX AND FCD**

FIGURE 4.18B

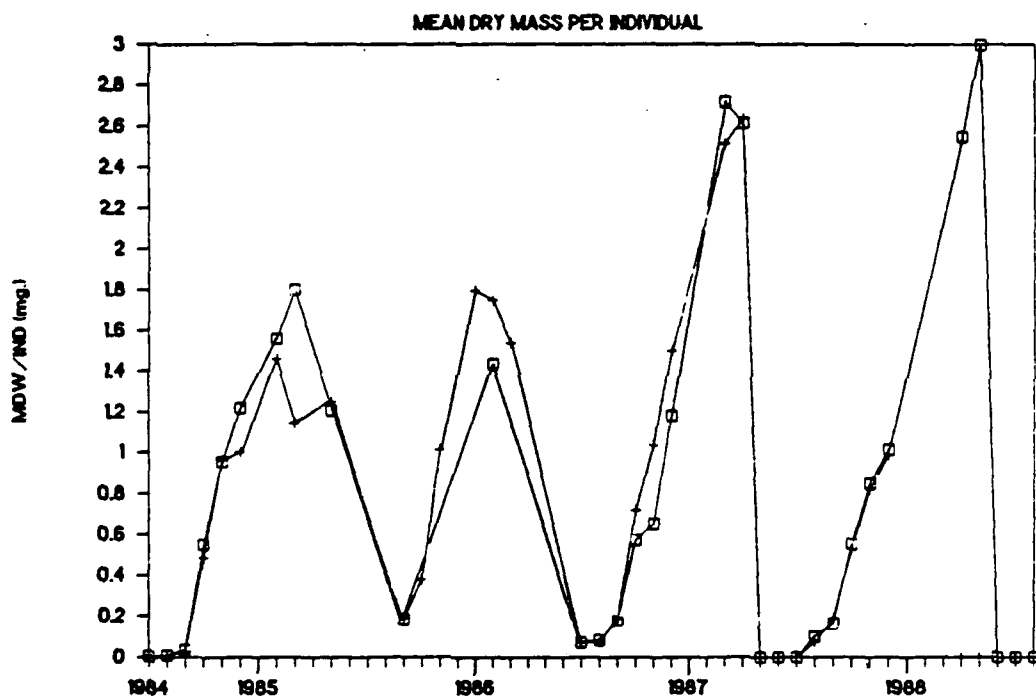
**E. SUBVARIA AT FEX AND FCD**

Figure 4.18A. Mean Dry Weight per individual (MDW/IND) for *Ephemerella invaria* at FEX (squares) and FCD (pluses) from July, 1984 to August 1988.

Figure 4.18B. Mean Dry Weight per Individual (MDW/IND) for *Ephemerella subvaria* at FEX (squares) and FCD (pluses) from July, 1984 to August 1988.



be staggered in late spring and early summer, as some mature nymphs are found after the major peak has passed. For both E. invaria and E. subvaria, their maximum MDW/IND values at FEX and FCD were in the springs of 1987 and 1988 at both sites. It is possible that the mild winter facilitated the development of a larger individual prior to spring emergence. In 1988 no individuals of either species were in FCD substrate samples (Figure 4.18 A, B). We suspect this is simply a sampling problem and that individuals were at that site.

c. Optioservus sp. No distinctive pattern emerges for this collector-gatherer elmids, probably owing to the fact that this holobiotic genus does not have discrete generations. It occurs in high numbers in the samples and we can gather considerable information as to larval and adult numbers. There is a tendency for larger larvae to occur in the winter (Fig. 4.19A). Certainly, from April through October the MDW/IND values were lower. Adults are most common in the late spring and summer months (Figure 4.19B). Nymphal maximum abundances tend to lag slightly behind maximum adult abundances (Figure 4.19C). After the 1986 summer adult peak, adult numbers did not approach zero during the autumn and winter as for other years. The following summer the adult peak at FEX was much lower than in previous summers. Their numbers decreased in the fall and winter of 1987. The following summer of 1988, the adult numerical peak was high at both sites. This pattern was reflected by larvae of Optioservus. As high numerical abundances of larvae lag behind those of adults, we suspect that when September 1988 samples are analyzed, larval numerical abundances will be as high as they were in previous years.

d. Glossosoma nigrior and Protoptila sp. are members of the trichopteran family, Glossosomatidae. The MDW/IND values for Glossosoma nigrior indicate that this species is univoltine, with its major emergence being between May and June (Figure 4.20A). The highest numbers of individuals occur just after the MDW/IND peak has passed, indicating that the high numbers are young of the year (Figure 4.12B). This species is more common at FEX than at FCD. The habitat at the FEX collection site may be more favorable for these collector-gatherers than the habitat at the FCD. This species is being used for grazer experiments by Tom Burton (Element 3). Data such as these may be useful to him as well as to work for this element.

e. Protoptila sp. The MDW/IND peak values indicate that this genus is univoltine, with its major emergence being in April and May (Figure 4.21A). Large-sized individuals were found at both sites in the summer of 1988. A mild prior winter may have contributed to their large MDW/IND values prior to pupation in 1988. The maximum number of individuals occurs just after the size peak. They are the young of the year, Figure 4.21B. Protoptila peak abundances vary between FEX and FCD. The variances probably are related to sampling differences.

FIGURE 4.19A

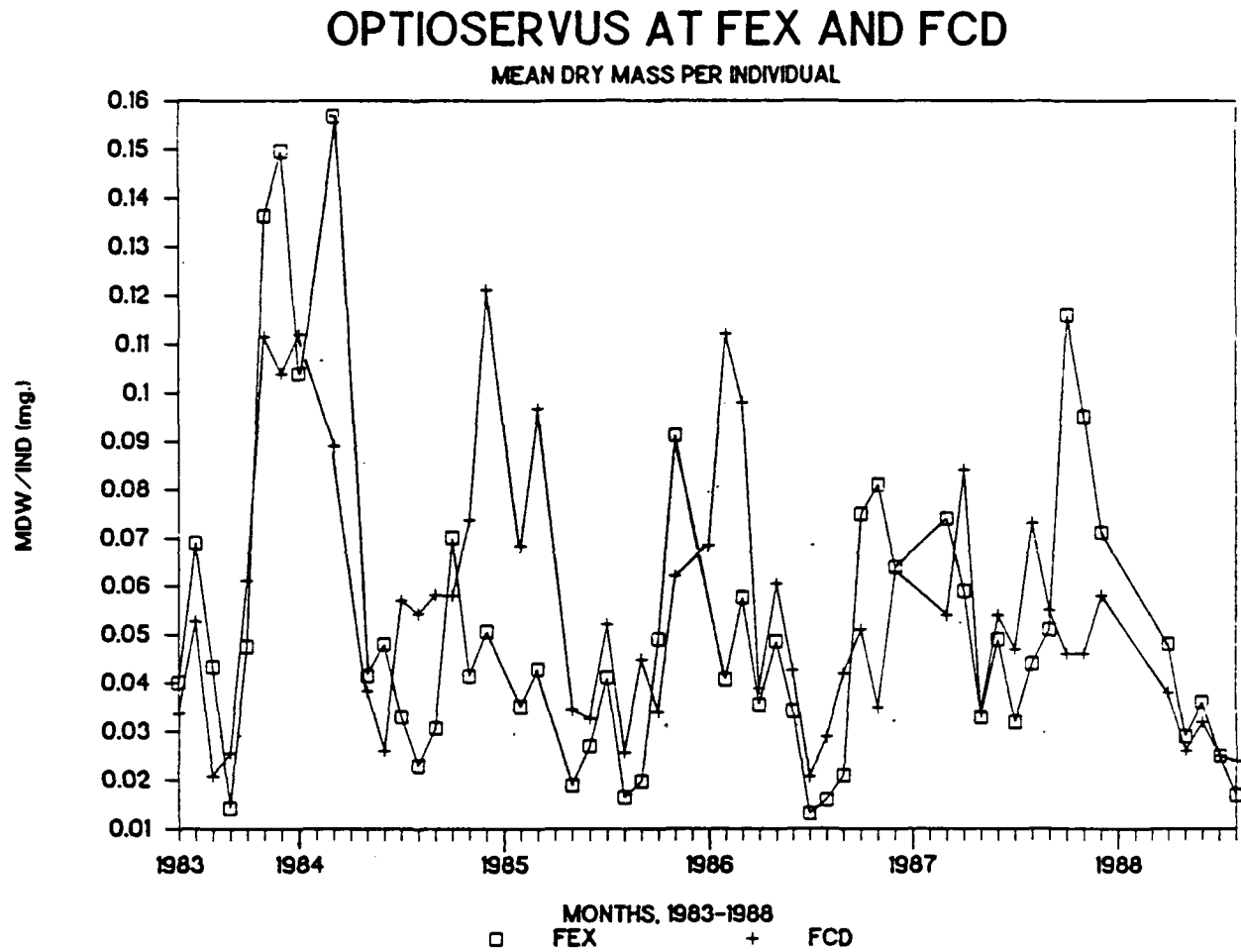


Figure 4.19A. Mean Dry Weight per Individual (MDW/IND) for Optioservus sp. at FEX and FCD from June, 1983 to August 1988.

FIGURE 4.19B OPTIOSERVUS ADULTS. FEX AND FCD

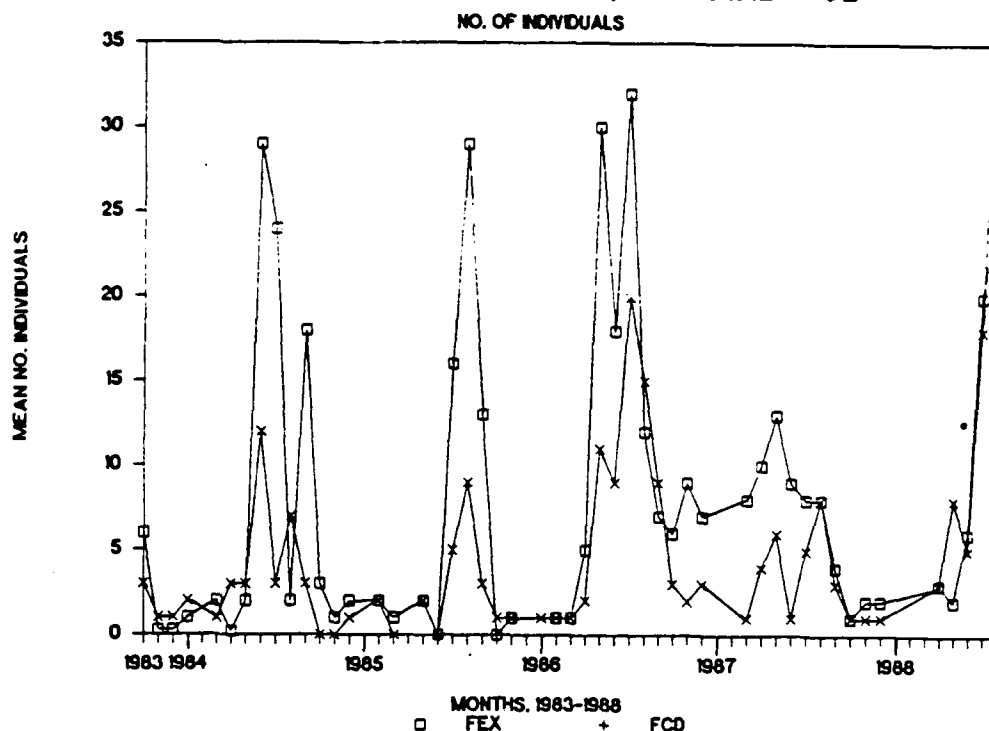


FIGURE 4.19C OPTIOSERVUS LARVAE. FEX AND FCD

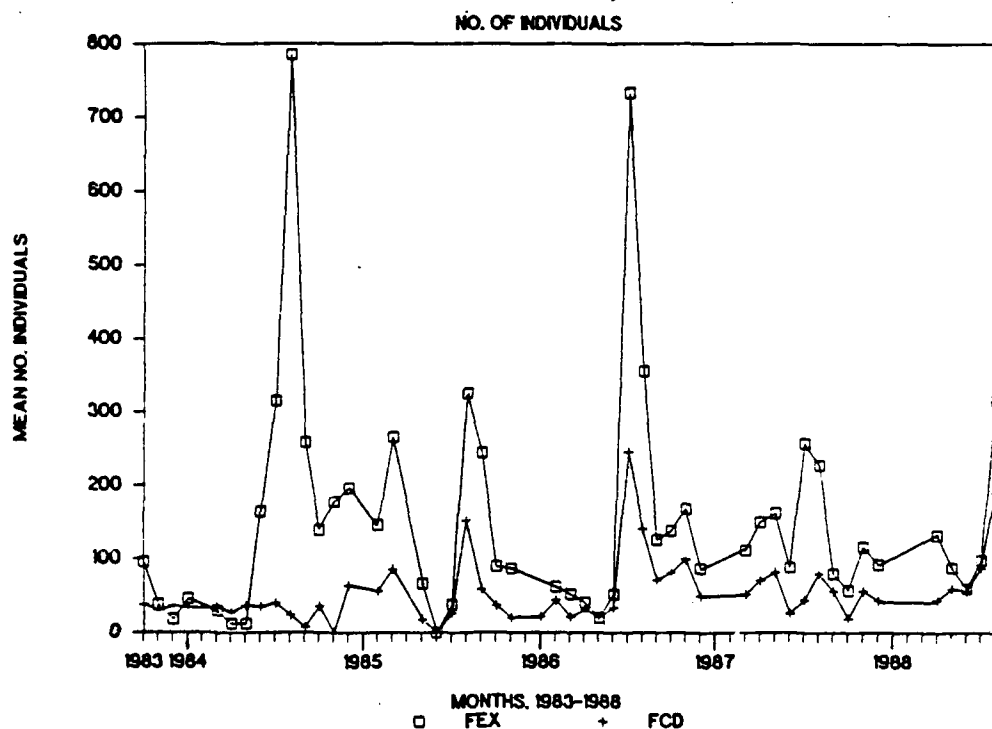


Figure 4.19B. Mean Number of Adults of Optioservus sp. at FEX and FCD from June, 1983 to August, 1988.

Figure 4.19C. Mean Number of Larvae of Optioservus sp. at FEX and FCD from June, 1983 to August, 1988.

FIGURE 4.20A GLOSSOSOMA NIGRIOR AT FEX AND FCD

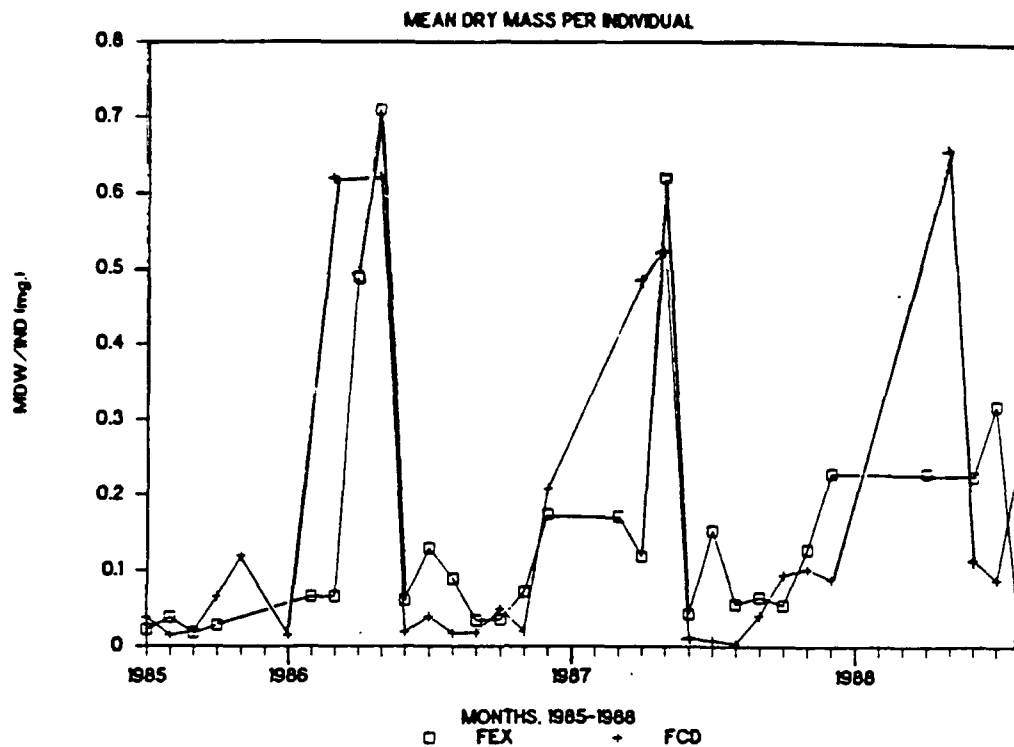


FIGURE 4.20B GLOSSOSOMA AT FEX AND FCD

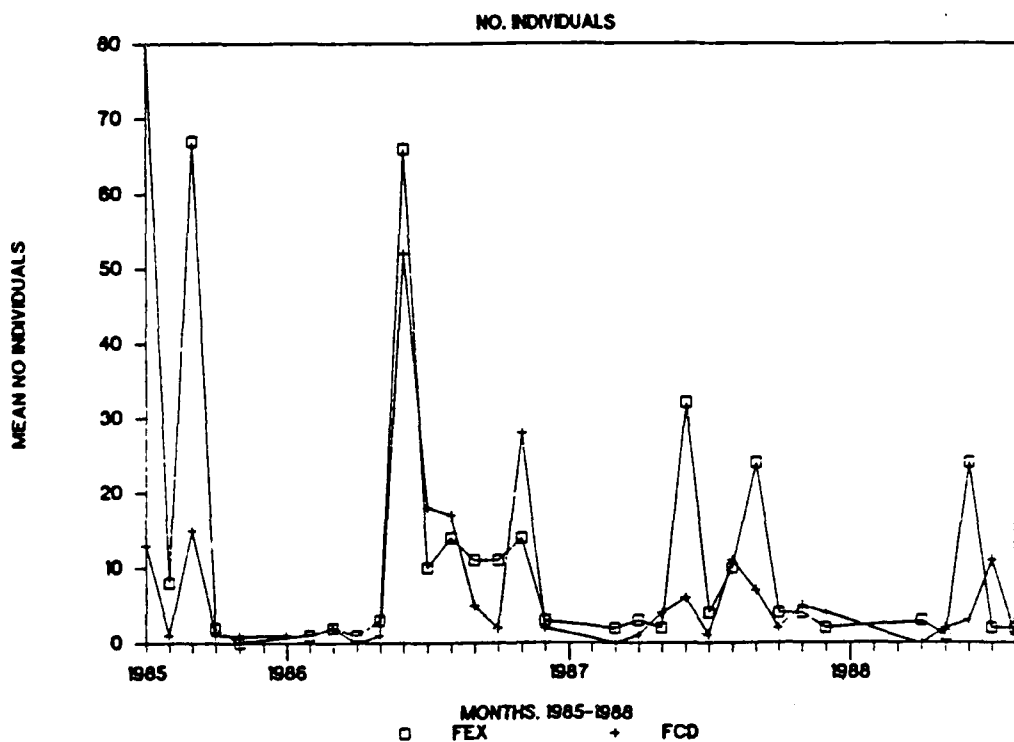


Figure 4.20A. Mean Dry Weight per Individual (MDW/IND) for Glossosoma nigror at FEX and FCD from June, 1983 to August, 1988.

Figure 4.20B. Mean Numbers of Individuals of Glossosoma nigror at FEX and FCD from 1985 to August, 1988.

FIGURE 4.21A PROTOPTILA AT FEX AND FCD

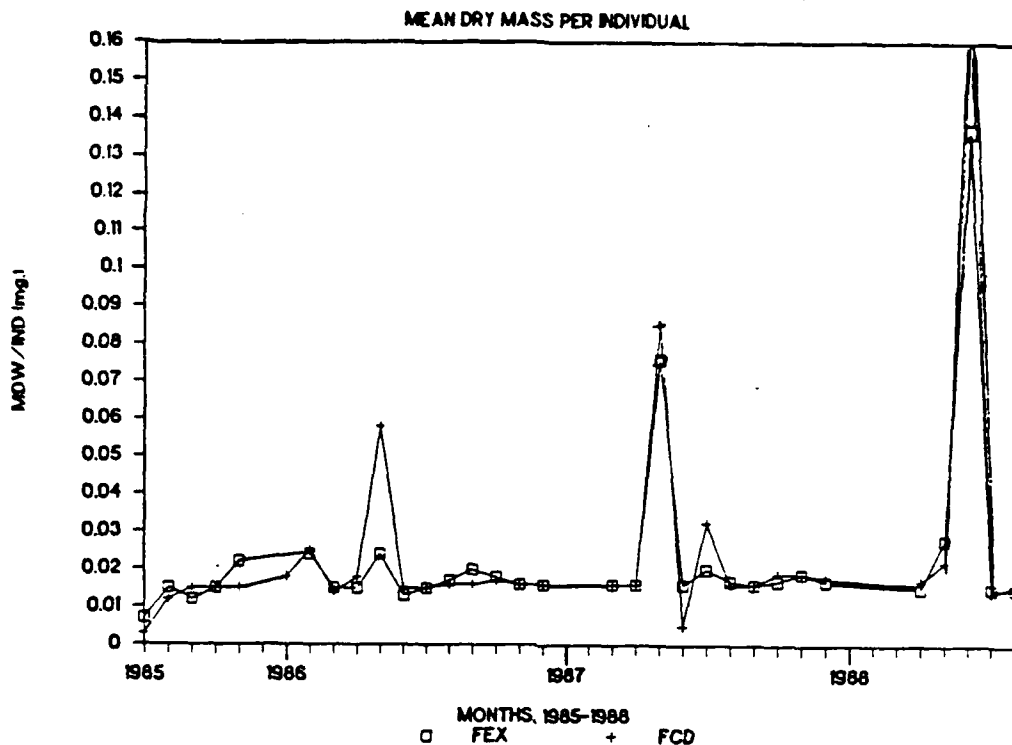


FIGURE 4.21B PROTOPTILA AT FEX AND FCD

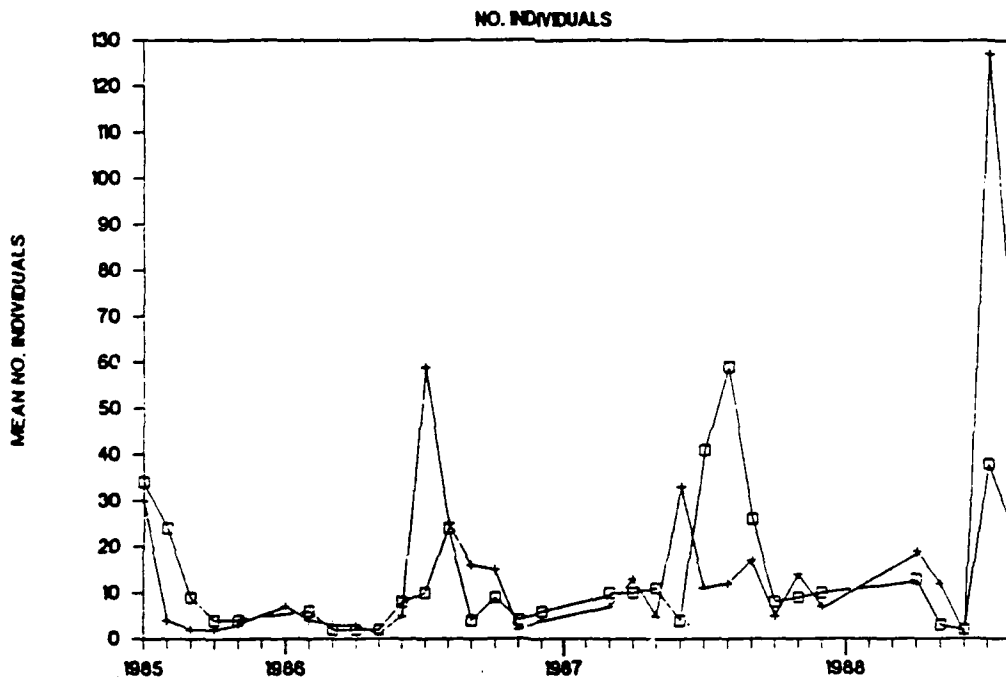


Figure 4.21A. Mean Dry Weight per Individual (MDW/IND) for Protoptila sp. at FEX (squares) and FCD (pluses) from June 1985 to August 1988.

Figure 4.21B. Mean Numbers of Individuals of Protoptila sp. at FEX (squares) and FCD (pluses) from June 1985 to August 1988.

### Future Plans for This Element

The same design and accumulation of data will continue as in the past. However, more sophisticated analyses will be performed. We now have three summers when ELF lines were activated. In the summers of 1986 and 1987 intensities and durations were low. In 1988 both intensities and durations were higher. By the end of the 1989 field season, sufficient data after activation of the current will be available for reasonable before and after comparison analyses. BACI tests (Stewart-Oaten et al. 1986) will be performed. We have, for now, targeted the best data sets for those analyses, as described in this Report. We will also take the most consistent data sets and regress cumulative degree days against them. There are many times when variances give more information than means, biological transition times being one of the most critical times. Variances will be analyzed during those periods. Transitional periods for aquatic insects occur during late fall and early spring. These periods will be analyzed separately from periods when variances were low, usually from June through September. Variability analyses will also be performed for pre- versus post-operational periods to see if FEX differs from FCD as a function of E.L.F. fields.

As suggested at the 1989 Annual Meeting, rare species may be more affected by ELF than the more common species we are monitoring, using MDW/IND values. As we have each of the taxa enumerated, along with their individual biomass values, we can retrieve additional, rare species. Of course, detection of differences is always difficult when numbers of individuals are low. The possibility exists that some rare species are being affected. Careful, detailed analyses of these rare species over time should be done in the event this is the case.

The next annual report will include a similarity matrix for taxa at FEX versus those found at FCD. Each year will be treated separately, and then a matrix for the species for the years before activation and a matrix after activation at each site will be made, as per the suggestion of one of the reviewers.

### Summary

Taxon diversity ( $H'$ ), evenness ( $J'$ ) richness ( $S$ ), and numbers of individuals had consistent depressions during winters and early springs; then had summer peaks over the entire five year period. Both water temperatures and discharge were correlated with diversity and richness from the spring to late fall each year at FEX and FCD. From 1986 onward, summer peaks lasted longer than in previous summers. The longer duration appears more related to mild winters of 1986 and 1987 than to any other factor, including activation of ELF lines in the summer of 1986. Future data and analysis will be used to test this assumption.

Chironomid abundances affected  $H'$  and  $J'$  values. The effects of chironomids on  $H'$  and  $J'$  were most pronounced at FCD, owing to the higher ratio of chironomid abundances relative to other species abundances. When chironomids were excluded from within-site analyses for benthic insects, correlation coefficients for  $J'$  with respect to  $H'$  were lower -- especially at FCD, the site that supports high numbers of chironomids relative to other species. This indicates that high numbers in the Chironomidae biases  $H'$  and  $J'$  for within-site comparisons. However, for between-site comparisons for any one parameter, the C.C. values are similar for data including chironomids as compared with data excluding them.

Total insect biomass had distinctive seasonal patterns over a five year period. These patterns were highly correlated with diatom densities and water temperatures at the two sites. From the summer of 1986 onward, the patterns showed less similarity. Each year, underwater solar radiation and water discharge was correlated with total insect biomass and diatom density from late spring through late fall.

Functional Feeding Groups (F.F.G.) were separated from insect total biomass values for analysis. Collector-gatherers showed the highest correlation coefficient values at FEX versus FCD. This functional feeding group contains many species that are being analyzed for changes in mean dry weight per individual values (changes in growth) and for changes in numbers of individuals. There appears to be no effect of ELF on those functional feeding groups. More data after ELF is fully operational are required before sufficient support of that view can be given.

Changes in MDW/IND values were consistent for the seven taxa monitored. The variance for the values are low, and if ELF affects any of those taxa, effects should be detected.

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## Element 5 - Movement Patterns of Selected Aquatic Invertebrates

Changes from the Original Synopsis - None.

### Objectives

To monitor short-term movement patterns of a dominant insect predator, the dragonfly Ophiogomphus colubrinus.

Extremely low frequency electromagnetic fields may affect orientation and movements of birds, fish and honeybees (Greenberg and Bindokas 1981, Larkin and Sutherland 1977, N.A.S. 1977, Williams et al. 1976). They also may affect movement and orientation of aquatic insects. We selected a highly abundant predator whose normal travel distances are short enough (0 - 5 m per 24 hr) to study feasibly. If E.L.F. alters orientation and movements rates of this predator, we expect, given the numbers of individuals and recapture success, to be able to detect differences, if they occur, under the influence of E.L.F.

### Materials and Methods

In June, July and August 1988, movement studies of naiads of the dragonfly, Ophiogomphus colubrinus, were done at FEX and at FCD. The same riffles at FEX and FCD were used from 1984 through 1988.

Prior to initiating mark-recapture studies, one-meter square grids were established with flagged stakes. Direction of flow, water depths and stream widths were taken prior to each mark-recapture series. Flow directions were mapped by placing an orange between each upstream stake and tracking the orange's course downstream. Depths were taken at marked flags. Velocities using a Gurley flowmeter were taken across the stream at 2 m intervals every five m downstream from the release sites after each recapture series.

Naiads were collected at least 500 m upstream of the study sites with a one meter square handscreen. The naiads were placed in a holding pan with stream water until sufficient numbers had been collected. No naiads smaller than 9 mm were used. Naiads were removed from the holding pan, blotted dry with a "Kimwipe", and marked with Testors enamel paint on the dorsal and lateral surfaces of the abdomen. They were placed in a second holding pan for approximately five minutes to allow the paint to dry. After drying, the naiads were placed in a third holding pan with stream water to test the adherence of the paint. At least 300 individuals were marked for each series.

Naiads were released in the upper end of the study grid one meter square area (figs 5.1, 5.2). The holding pan with

FIGURE 5.1

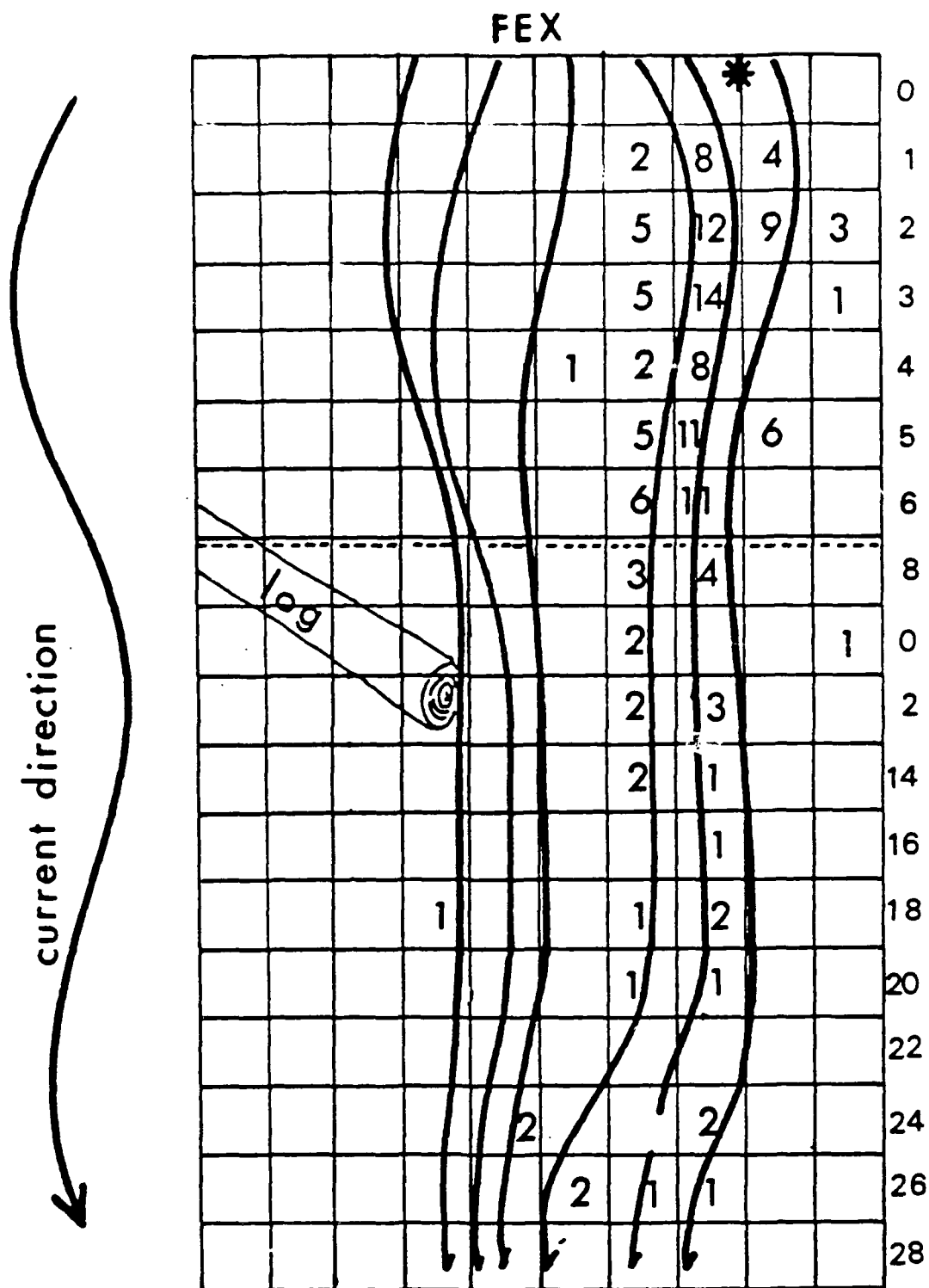


Figure 5.1 Map of FEX with number of marked animals recaptured in one meter square grids. 24 Hour Recapture, June 21, 1988. Asterisk marks release point, arrow indicates flow direction.

FIGURE 5.2

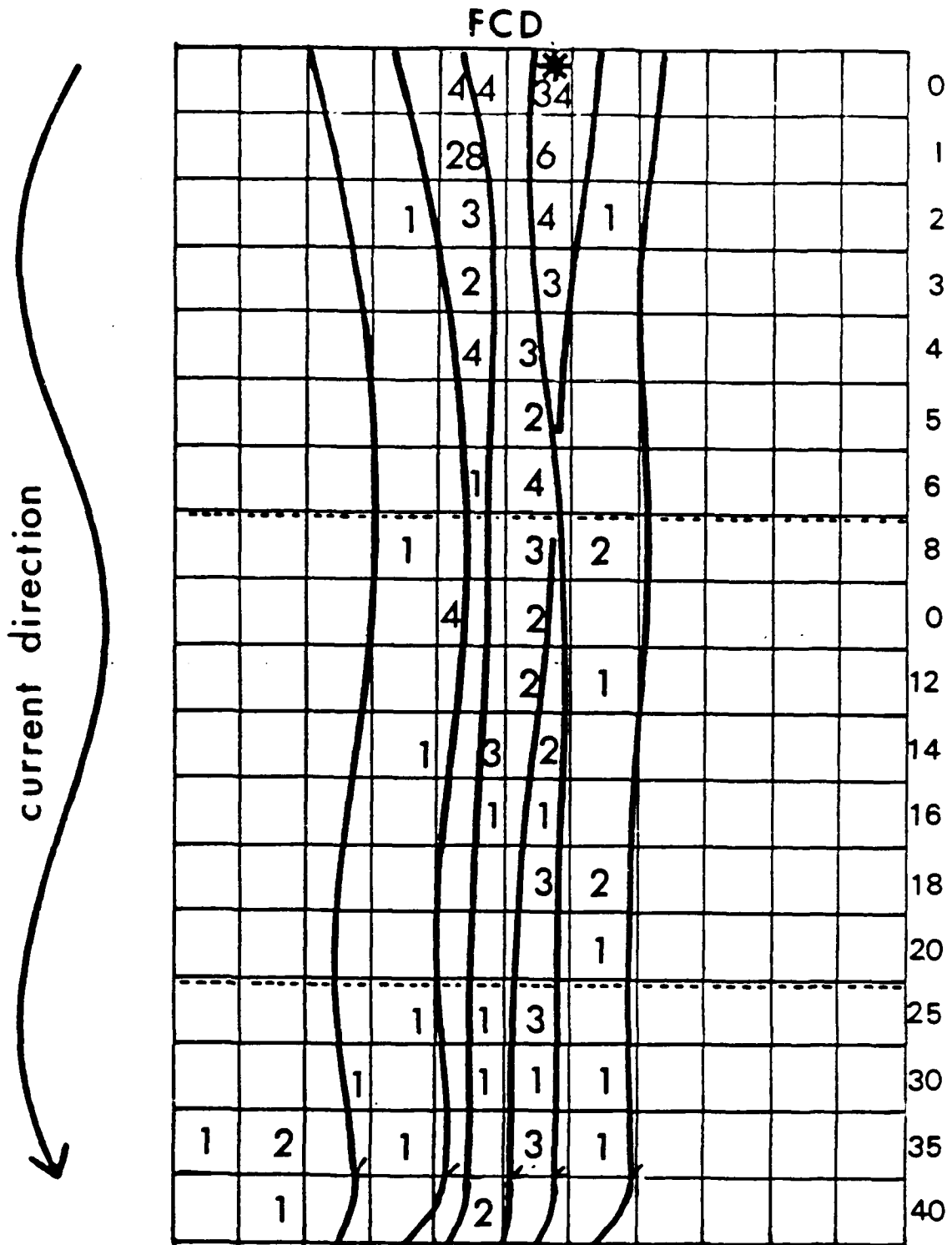


Figure 5.2 Map of FCD with number of marked animals recaptured in one meter square grids. 24 Hour Recapture, June 24, 1988. Asterisk marks release point, arrow indicates flow direction.

the marked individuals, was placed in the stream at the upper end of the release area. Wooden baffles upstream of the release site allowed naiads to settle in the release area.

Twenty-four hr after the initial release, the grid was kickscreen sampled in 1 m square areas, beginning at the downstream portion of the study site and ending 2 m above the release site. The number of marked individuals and unmarked individuals collected from each square of the grid were recorded and these naiads were placed in a holding pan. After the entire site was kicked, leaving a border of at least 2 square meters where no marked animals were recaptured, all previously marked animals were remarked with a new color. Additional unmarked animals were marked with that new color, giving a total of at least 300 individuals. All animals were again released at the original release site. Forty-eight hr later, the area was resampled.

Two 24 hr and two 48 hr recapture series were completed at each of the sites. Studies began in late June and ended in August of 1988. Intensities and duration of electromagnetic E.L.F. activity were not known by the investigators during the studies.

Percent recapture success, distances and directions travelled, and comparisons between and within sites for distances travelled were made, using Chi Square analysis. Population estimates, based on the Lincoln Index (Southwood, 1966) were determined for 24 hr release experiments.

## Results

### 1988 Data

Physical Differences Between FEX and FCD.-- Mean discharge values were similar between FEX and FCD during all the studies (e.g., June study; FEX: 46 cm/sec, FCD 43 cm/sec,  $T = 0.638$ , d.f. = 12, and  $p = 0.268$ ). Mean water depths, however, did differ significantly between the sites; e.g., June study; FEX: 16.5 cm., FCD = 23.7 cm,  $T = -5.80$ , d.f. = 94,  $p < 0.0001$ . Water depths were lower in June and early July than in late July and early August (August mean depths: FEX, 24.1 cm, FCD, 29.9 cm).

Mark-Recapture Results.-- Naiads of O. colubrinus were rather sessile. The net movement direction was downstream, and the marked animals were recaptured along the current flows below the release site. Figures 5.1 and 5.2 show the current flow pattern, along with numbers of marked animals found in each meter square grid after the first 24 hr experiment at each site. The pattern of recovery was similar to flow patterns in that most animals were recovered along major flow patterns. Distances travelled downstream were usually short. Table 5.1 and figures 5.3A,B and 5.4A,B show

that over 60% of recaptured individuals were taken within 6 m of the release site except for two series. One deviation occurred for the 24 hr recapture at FEX June 21 (Figure 5.3A). The other deviation occurred for the 48 hr recapture series at FEX June 23 (Figure 5.4B). On 23 June fewer than 30% of the marked animals were collected within 6 m of the release site.

Table 5.1 shows maximum, median and geometric mean distances animals travelled at FEX and FCD. The median distance moved by the dragonflies at FEX was longer than at FCD for June. Most animals remained at each of the release sites in July and August, as reflected by median distances. After completion of our 1988 summer field season, duration, direction, and intensity of ELF electromagnetic fields were supplied by IITRI. North-south activation of ELF lines at 75 amps occurred during the June, July, and early August periods. Although animals moved farther at the experimental site in June than in July, duration of current potentially experienced by the animals was similar at the FEX site: June 24-hour recapture, 9 exposure hours; July 24-hour recapture, 8.5 exposure hours. June 48-hour recapture, 9 exposure hours; July 48-hour recapture, 10.3 exposure hours. If ELF exposure affected the animals, it did so differentially in June as compared with July. Exposure duration for the animals was similar for those animals during each of the studies. On the other hand, animals that were used in the July studies had been exposed for one month longer than the ones used in the June study, prior to being marked. If there were any ELF effect, it would appear that animals earlier in the season and, therefore, under a shorter exposure period for the summer, responded by moving farther distances in 1988.

TABLE 5.1

Distances and Directions Travelled by Ophiogomphus colubrinus at FEX and FCD after 24 and 48 Hours

TIME	MAXIMUM DISTANCE (Meters)	MEDIAN DISTANCE (Meters)	GEOMETRIC MEAN (Meters)
<u>FEX SITE</u>			
24 hrs			
21/VI/88	24	3	4.86
48 hrs			
23/VI/88	27	10	9.41
24 hrs			
27/VII/88	29	0	1.03
48 hrs			
29/VII/88	11	0	0.31

Table 5.1, continued

TIME	MAXIMUM DISTANCE (Meters)	MEDIAN DISTANCE (Meters)	GEOMETRIC MEAN (Meters)
----- FCD SITE			
24 hrs			
24/VI/88	38	1	5.41
48 hrs			
26/VI/88	41	2	8.17
24 hrs			
2/VIII/88	36	0	2.33
48 hrs			
4/VIII/88	39	0	5.33

Table 5.2 gives the overall percent recapture success as well as population estimates for both sites. Recapture success was always over 45% with one exception (48 hr recapture at FEX in June). In that case, animals could have moved farther downstream than we sampled even though we sampled for at least 2 m downstream from the last recovered marked animals.

TABLE 5.2

Percent Recapture Success  
and Population Estimates of O. colubrinus

SITE (Date)	PERCENT RECOVERY		POPULATION ESTIMATES (from 24 hr data)
	24 hrs	48 hrs	
-----			
FEX			
June 21, 23	47.2	34.9	32.3 animals/sq.meter
July 27, 29	73.9	47.7	24.8 animals/sq.meter
FCD			
June 24, 26	62.3	52.0	21.37 animals/sq.meter
Aug. 2, Aug. 4	66.7	51.0	24.2 animals/sq.meter

Figures 5.3A,B and 5.4A,B show the percent marked animals recaptured across the stream every two meters downstream from the release site (zero on the x axis) to the last recapture site after 24 and 48 hrs. Figure 5.3A presents 24 hr recapture data from FEX and Figure 5.3B presents data from FCD. The June recapture at FEX differed from the other 24 hr recaptures. Not only was the percent return lower than for other series (Table 5.2), but most of the animals were

FIGURE 5.3A FEX: PERCENT RETURN AFTER 24 HRS. 1988

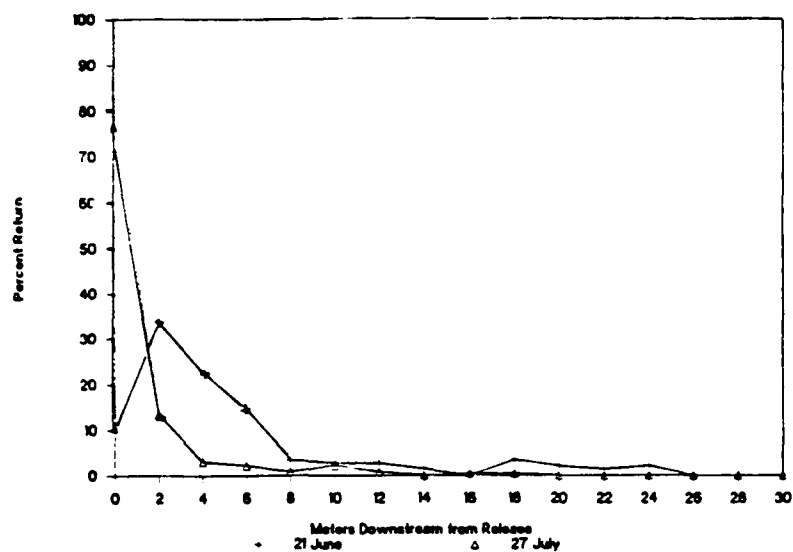


FIGURE 5.3B FCD: PERCENT RETURN AFTER 24 HRS. 1988

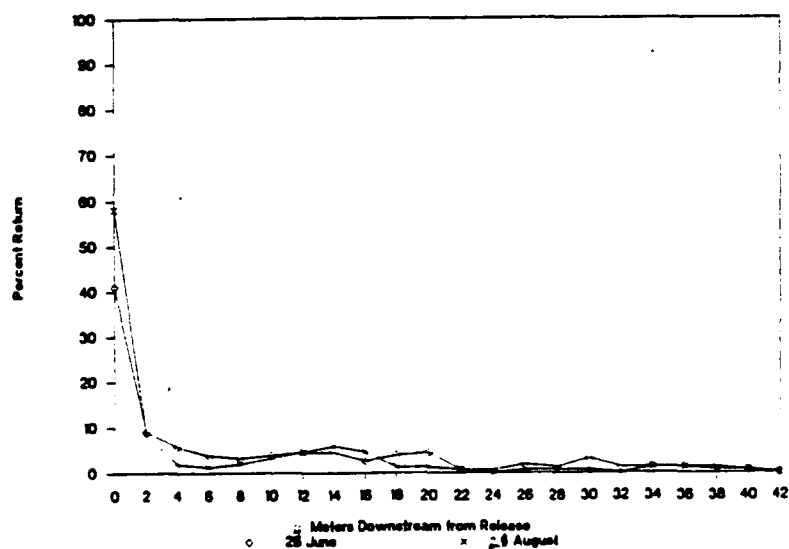


FIGURE 5.3A. 24 Hr. recaptures: Percent recaptured every 2 M from release point to farthest downstream recovery site at FEX. Pluses: 21 June, triangles: 27 July.

FIGURE 5.3B. 24 Hr. recaptures: Percent recaptured every 2 M from release point to farthest downstream recovery site at FCD. Pluses: 24 June, triangles: 2 August.

FIGURE 5.4A FEX: PERCENT RETURN AFTER 48 HRS. 1988

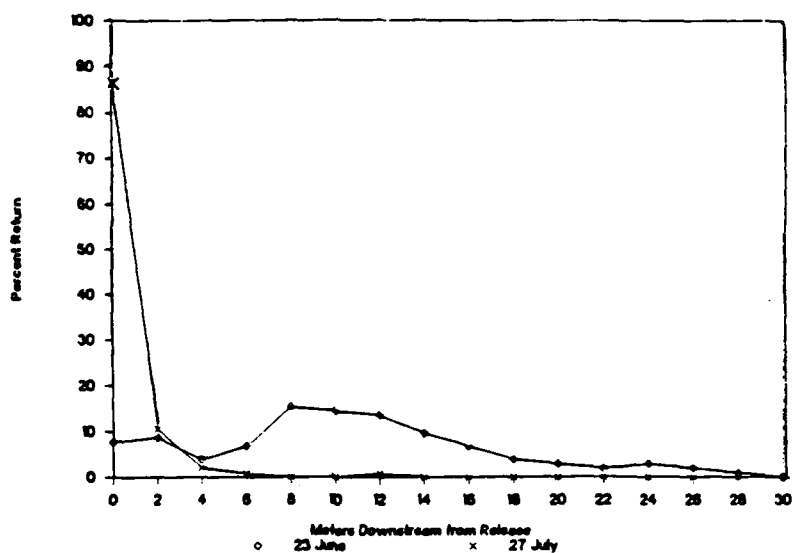


FIGURE 5.4B FCD: PERCENT RETURN AFTER 48 HRS. 1988

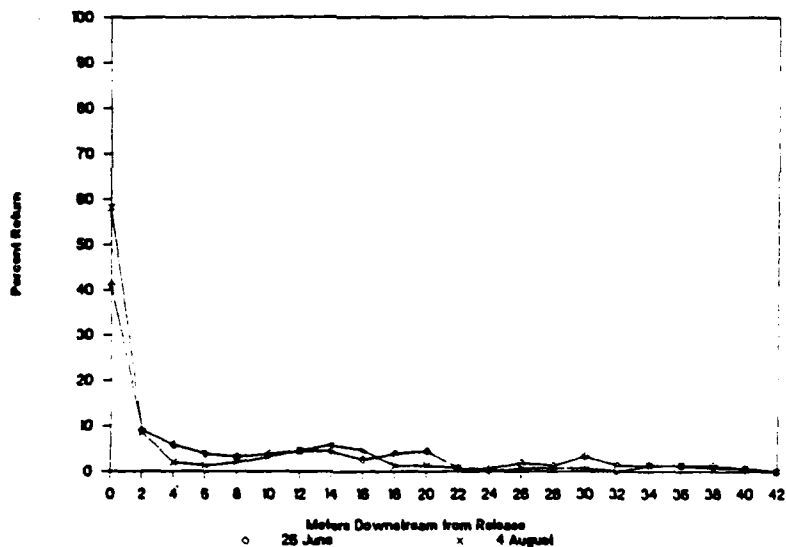


Figure 5.4A. 48 Hr recaptures: Percent recaptured every 2 M from release point to farthest downstream recovery site at FEX. Pluses: 23 June, triangles = 27 July.

Figure 5.4B. 48 Hr recaptures: Percent recaptured every 2 M from release point to farthest downstream recovery site at FCD. Pluses: 26 June, triangles = 4 August.



recovered farther downstream in June at FEX. Rainfall in June was exceedingly low (less than 2 cm) and mean water depths were low (FEX = 16.5 cm). Low water and warm temperatures may have affected movement of the animals more than the effects of E.L.F. Figure 5.4A and 5.4B presents 48 hr recapture data from FEX and FCD, respectively. Again, data from the 48 hr recapture at FEX on 23 June differed from other 48 hr recapture data. A lower percent return was found just below the release site and more animals were found farther downstream.

Chi Square tests were used to compare distances the animals moved at FEX and FCD after 24 and 48 hrs in 1988 (Table 5.3). There were significant differences between sites for the 24 hr recaptures in 1988. The signs for differences between observed and expected show that there is a larger difference at FEX for the June versus July recapture distances than for the June versus early August recapture distances at FCD (Figure 5.3A and 5.3B). Animals travelled farther distances at FEX in June than in July. This was also true for FCD for June versus early August; however, at FCD the deviations between observed values and expected values were much smaller.

TABLE 5.3

Chi Square Test for Distances Moved by Ophiogomphus colubrinus after 24 Hours at FEX and FCD, 1988

Meters downstream	Differences Between Observed & Expected			
	FEX SITE		FCD SITE	
	June 21	July 27	June 24	August 2
0 - 2	-55	+33	-7	+29
3 - 4	+18	-7	-2	-9
5 - 6	+28	-14	-4	-11
7 - 8	+3	-1	+3	-4
9 - 10	0	-4	+7	-3
11 - 15	+3	-3	+2	-3
16 - 20	+3	-4	+1	+1

Chi Square = 206.28, d.f. = 18,  $p < 0.0001$

There were also significant differences between sites and recapture dates for the 48 hr recaptures in 1988, Table 5.4.

TABLE 5.4

Chi Square Test for Distances Moved by Ophiogomphus colubrinus after 48 Hours at FEX and FCD in 1988

Meters downstream	Differences Between Observed & Expected			
	FEX SITE		FCD SITE	
	June 23	July 29	June 26	August 4
0 - 2	-47	+47	-11	+11
3 - 4	+3	-2	+3	-3
5 - 6	+3	-5	+5	-2
7 - 8	+12	-7	-1	-4
9 - 10	+11	-5	-3	-3
11 - 15	+16	-18	+1	+1
16 - 20	+2	-10	+6	+1

Chi Square = 208.88, d.f. = 18,  $p < 0.0001$ .

#### 1985 Through 1988 Comparisons

Twenty-four and 48 hr recapture data from 1985 through 1988 were analyzed for across year comparisons. Figure 5.5 depicts distances moved after 24 hr at FEX in 1985, 1986, and 1987. Figure 5.6 shows distances moved after 24 hr at FCD for those years. The low and high extremes for percent marked found at the release point occurred in 1988 at FEX (Figure 5.3A). The same was not true for FCD (Figure 5.3B). Chi square analyses were performed; they include only late June and early July to minimize possible temporal differences in movement patterns. Table 5.5 shows Chi Square results for FEX and Table 5.6 shows results for FEX after 24 hr series from 1985 through 1988.

TABLE 5.5

Chi Square Tests for Distances Moved by Ophiogomphus colubrinus after 24 Hours at FEX in 1985 Through 1988

Meters Downstream	Differences Between Observed and Expected			
	1985 July 9	1986 June 24	1987 June 26	1988 June 21
0 - 2	-18	-37	+75	-20
3 - 4	+3	+18	-25	+4
5 - 6	+10	-2	-25	+17
7 - 8	+8	-1	-6	-1
9 - 10	0	+7	-5	-2
11 - 15	-1	+8	-8	0
16 - 20	-2	+7	-6	+2

Chi Square = 248.66, d.f. = 18,  $p < 0.0001$

FIGURE 5.5 FEX, 24 HOURS. 1985 - 1986

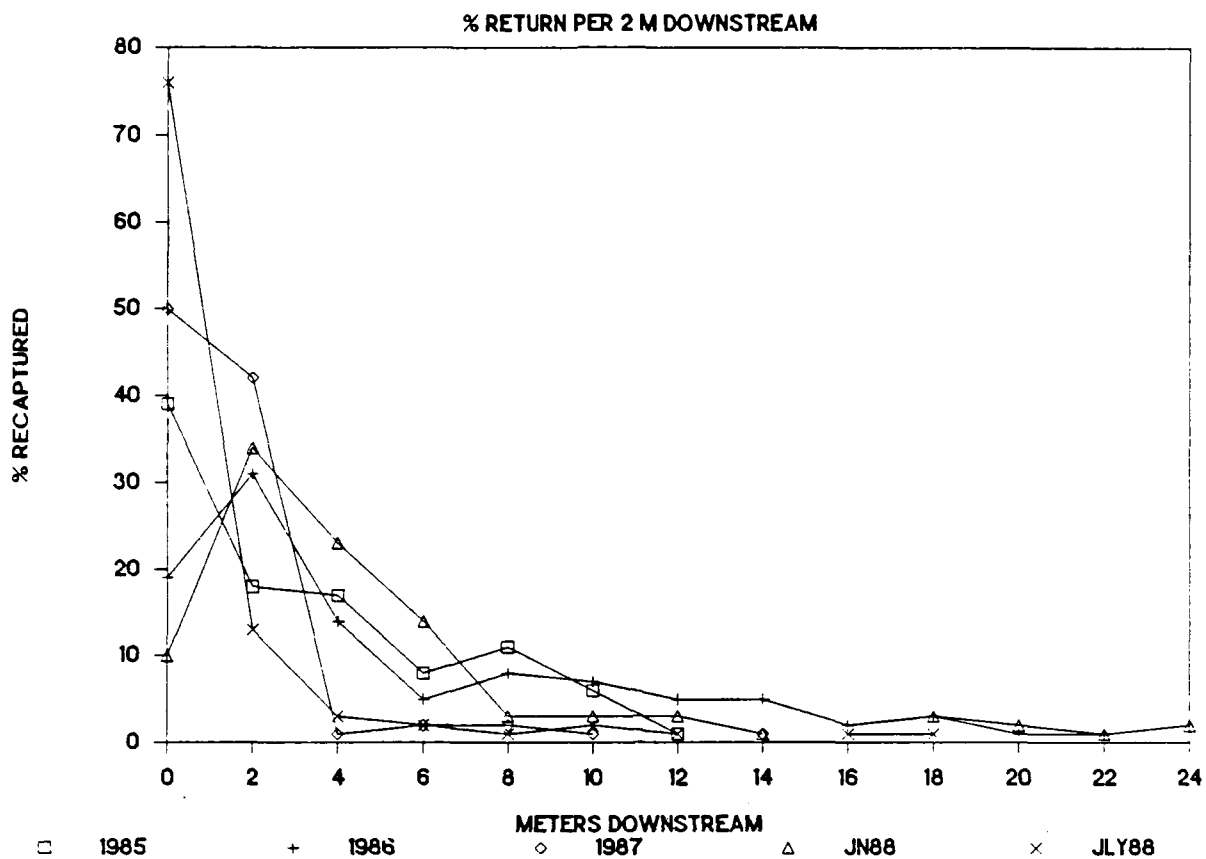


Figure 5.5. 24 Hour recaptures: percent recaptured every 2 meters from release point to farthest downstream recovery site at FEX; 1985, 1986, and 1987.

FIGURE 5.6 FCD, 24 HOURS. 1985 - 1986

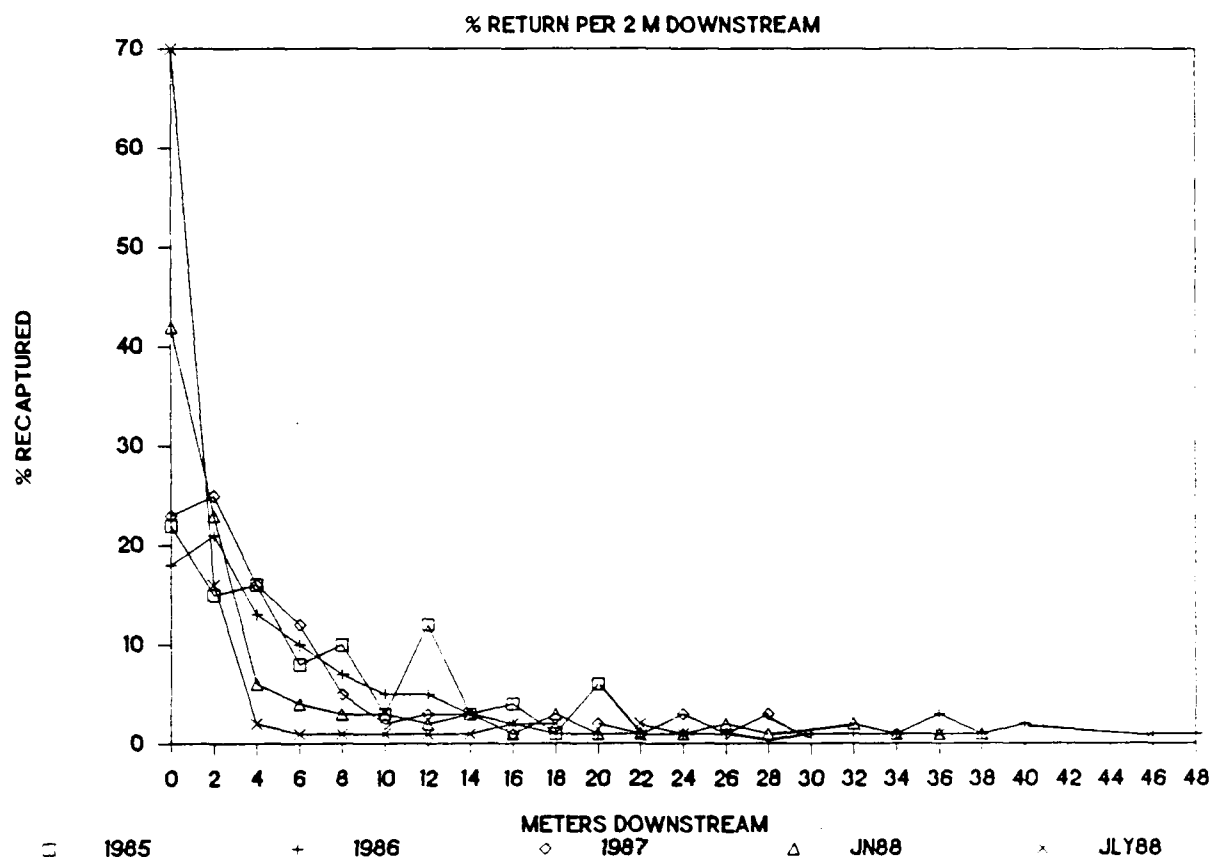


Figure 5.6. 24 Hour recaptures: percent recaptured every 2 meters from release point to farthest downstream recovery site at FCD; 1985, 1986, and 1987.

The variance among years was high. If only 1987 and 1988 were compared, one could hypothesize that the 75 amp. E.L.F. current in 1988 affected movement patterns. Yet, 1985 and 1986 data are more similar to 1988 than to 1987 patterns at FEX.

TABLE 5.6

Chi Square Tests for Distances Moved by Ophiogomphus colubrinus after 24 Hours at FCD in 1985 through 1988

Meters Downstream	Differences Between Observed & Expected			
	1985 July 16	1986 July 1	1987 June 30	1988 June 24
0 - 2	+6	-26	-25	+44
3 - 4	+10	+6	+4	-20
5 - 6	-1	+4	+11	-14
7 - 8	-7	+5	+9	-7
9 - 10	-4	+5	-4	+3
11 - 15	-2	+7	-1	-4
16 - 20	-2	-1	+6	-2

Chi Square = 134.95, d.f. = 18,  $p < 0.0001$

The variance for animal movement patterns at FCD was also high. Chi square values for each site were significant, although FCD had a lower value. Data from 1985 and 1988 at FCD were similar; whereas, 1986 and 1987 data were similar.

Figures 5.7 and 5.8 show percent return after 48 hr for percent marked animals recovered every 2 m downstream at FEX and FCD, respectively, in 1985, 1986, and 1987. The same event as for the 24 hr recapture series occurred for the 48 hr series -- extremes occurring in 1988 only at FEX. Chi square tests for the 48 hr data appear in Table 5.7 (FEX) and Table 5.8 (FCD).

TABLE 5.7

Chi Square Tests for Distances Moved by Ophiogomphus colubrinus after 48 Hours at FEX in 1985 through 1988

Meters Downstream	Differences Between Observed & Expected			
	1985 July 11	1986 July 31	1987 June 28	1988 June 23
0 - 2	-10	-4	+31	-18
3 - 4	+10	+17	-15	-12
5 - 6	0	+9	-7	-1
7 - 8	+1	-7	-1	+7
9 - 10	-2	-7	+2	+7
11 - 15	-2	-9	-4	+15
16 - 20	+3	+1	-6	+2

Chi Square = 128.39, d.f. = 18,  $p < 0.0001$

FIGURE 5.7 FEX, 48 HOURS. 1985 - 1988

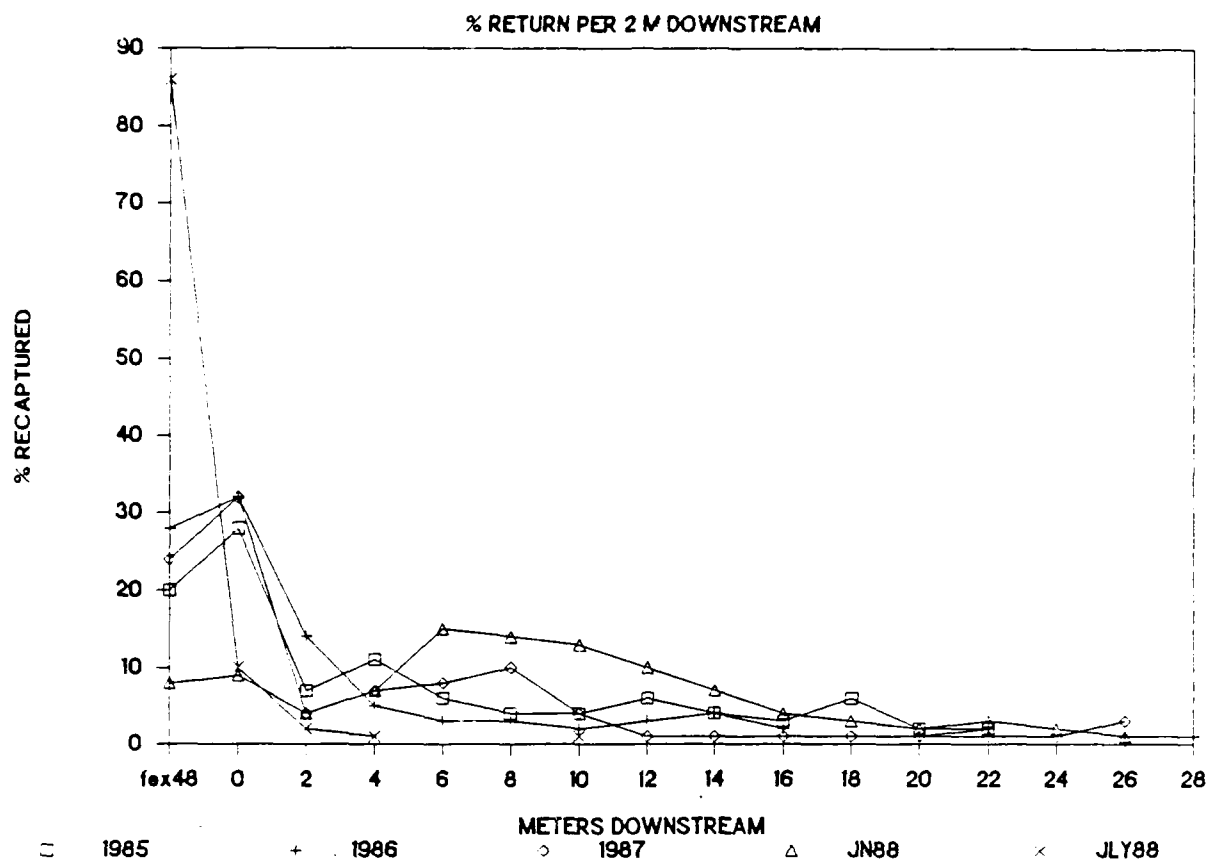


Figure 5.7. 48 Hour recaptures: percent recaptured every 2 meters from release point to farthest downstream recovery site at FEX; 1985, 1986, and 1987.

FIGURE 5.8 FCD, 48 HOURS. 1985 - 1988

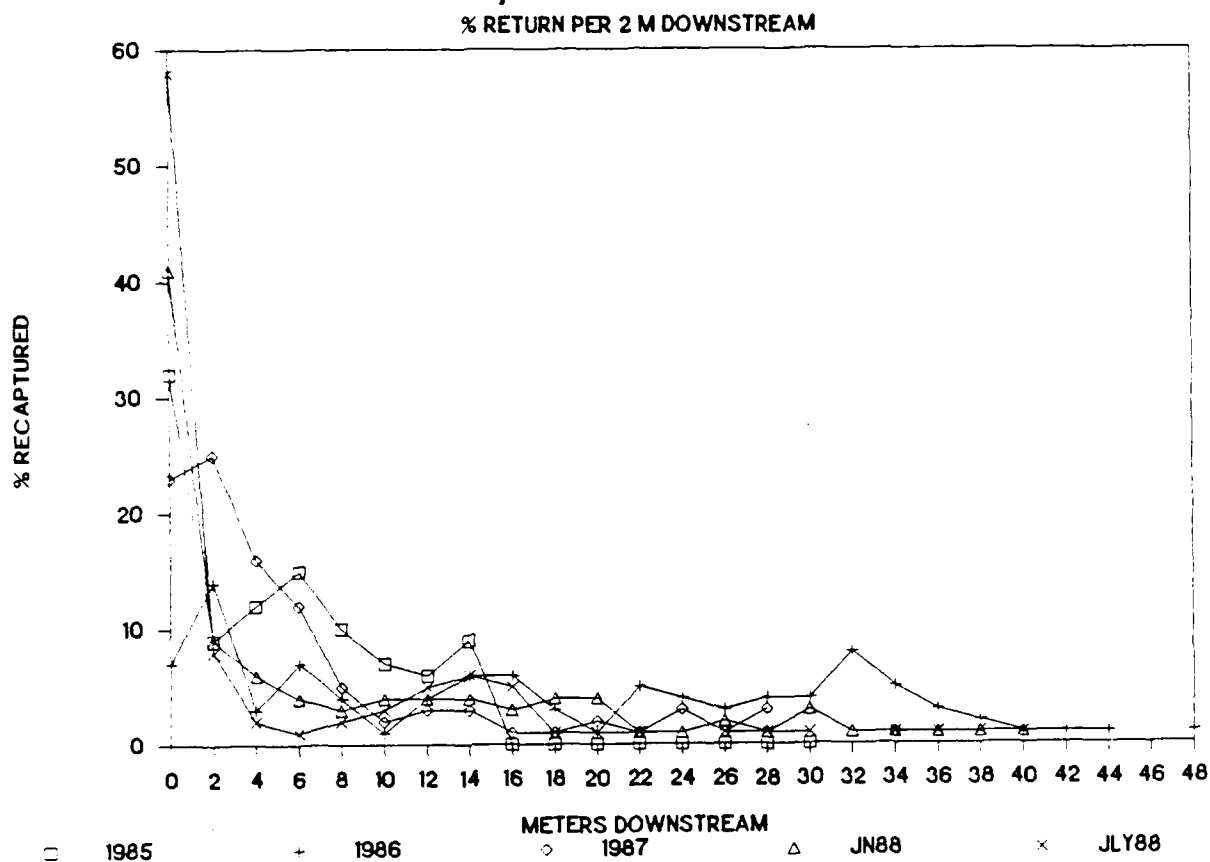


Figure 5.8. 48 Hour recaptures: percent recaptured every 2 meters from release point to farthest downstream recovery site at FCD; 1985, 1986, and 1987.

TABLE 5.8  
Chi Square Tests for Distances Moved by Ophiogomphus  
colubrinus after 48 Hours at FCD in 1985 through 1988

Meters Downstream	Differences Between Observed & Expected			
	1985 July 18	1986 August 7	1987 July 2	1988 June 26
0 - 2	-7	-11	-11	+28
3 - 4	-4	+5	+14	-15
5 - 6	-1	-4	+7	-4
7 - 8	+4	+1	+4	-8
9 - 10	+6	+1	0	-6
11 - 15	+2	+1	-4	+2
16 - 20	0	+7	-10	+3
Chi Square = 102.42, d.f. = 18, p < 0.0001				

As for the across year comparisons for 24 hr series, the 48 hr series showed high variance over time. No general pattern emerged for FEX over the years. However, a pattern was visible for FCD. There, 1985 through 1987 data were more similar to each other than were the 1988 data as compared with previous years. Given that FCD is the reference site, effects of E.L.F. cannot be invoked to account for these differences. Rather, seasonal differences across years may be related to differences in distances the animals travelled from 1985 through 1988.

### Discussion

**1988 Studies.**--This dragonfly predator, in searching prey, appears to travel short distances during summer months. Owing to its rather sessile habits, high recapture success is possible. Also, movement patterns can be determined with good reliability. On the other hand, one assumption for population estimates based on mark-recapture studies cannot be met: We cannot assume that marked animals resort themselves randomly in the population after release. Rather, they are rather sessile and they also appear to respond to current flow patterns more than to the substrate when they do move. Thus, population estimates are subject to question. We chose to base population estimates using grids that included marked animals. Bias owing to non-random reassortment were hopefully minimized by excluding grids devoid of marked animals.

Percent recapture rates were high (mean = 54.5%, n = 8). We are confident that distances and locations of recaptures reflect natural movement patterns with only one caveat, that being potential initial disturbance of the animals.



The most powerful results from this element are those showing distances travelled over time. In 1988, June data differed between sites for the 24 hr and 48 hr series (figs. 5.3A, 5.3B). More animals than expected were recaptured downstream of the immediate release site at FEX (tables 5.3, 5.4). In contrast, late July-early August data showed that more animals than expected were found at the release sites of FEX and FCD (tables 5.3A, 5.3B). These differences between collection periods may be related to seasonal changes in movement patterns of the predators themselves. Rainfall was meager in June. That coupled with lower depths, lower velocities and warmer water temperatures may have triggered increased movement rates by the animals.

The largest differences between observed and expected numbers of animals recovered after 24 and 48 hrs were at FEX rather than at FCD. The increased variability could be natural physical differences in sites, animals at sites, E.L.F. effects, undetected differences in techniques or a combination of any of these factors. As for now, temporal differences appear to be more variable than site differences.

#### Comparison With Earlier Studies

Percent recapture success steadily increased over the years (Table 5.9), owing to improvements in sampling techniques. We always had two people with handscreens adjacent to one another when sampling (initiated in 1986), and we constructing a baffle directly upstream of release sites to facilitate quick settling of marked animals (initiated in 1987). In 1986 half of the 48 hr recapture data were confounded by sampling between 24 and 48 hrs. Reporting of animals not recaptured after 24 hrs but recaptured after 48 hrs is no longer done. Animals undetected in their recapture "day" are recorded but those numbers are not reported.

Median distances moved were generally shorter in 1987 and 1988 (Table 5.9). Addition of a baffle to reduce flow rates at the release quadrat for one-half hour during release of the animals may have helped animals to settle and adhere. Even though handscreens held below the release site caught floating marked animals for re-release, reduced disturbance at initial releases appeared to enhance settling.

TABLE 5.9

Distances Travelled and Percent Recapture Success Results at  
FEX and FCD from 1985 through 1988

Year	Median Dist.(m)	Maximum Dist.(m)	Percent Recapt.	Median Dist.(m)	Maximum Dist.(m)	Percent Recapt.
	F E X	S I T E		F C D	S I T E	
24 Hr.						
1985	5	13	31.45	3	17	33.85
1986	3	23	43.70	6	56	46.67
1987	0	15	55.21	5	36	50.67
1988	1	24	50.55	0	37	64.50
-----						
48 Hr.						
1985	5	25	30.92*	6	17	27.20*
1986	2	22	23.33*	11	40	41.14*
1987	1	28	65.83	3	36	49.68
1988	5	19	41.30	1	40	51.50

\* = At least one recapture series with an intervening sampling  
which disturbed site

Movement patterns of the animals varied within and between sites over the years. As variability was high prior and after E.L.F. activity, an increase in numbers of marking series at both sites for future years will be necessary to determine if E.L.F. differentially affects movements of the dragonflies.

#### Plans for the Future

The variability shown by the data within and between years led us to increase numbers of mark-recaptures in future years. This will be necessary in order to determine if E.L.F. effects alter movements of these animals. The labor-intensive nature of the experiments negates series being done every week at each site. In 1989, we plan on conducting at least four 48 hr mark-recapture experiments at each of the two sites. Each pair of experiments (one at FEX and FCD) will be done within a four day period. By having a large series of recaptures in one season, data can be used to compare the experimental site and the reference site over one season to minimize the yearly natural biological variation. The trade-off of increasing numbers of 48 hr series is to no longer conduct 24 hr experiments. Forty-eight hr recapture data shows lower variability and was chosen over the 24 hr experiments for that reason.

## Summary

Naiads of O. colubrinus travelled in a downstream direction at both sites for all mark-recapture studies. Percent recapture success is high (usually from 40 to 50%) making us rather confident that the data reflect the actual movement patterns of this predator. Yearly and seasonal variation in distances travelled by the dragonflies at each of the sites has prompted us to initiate more series in future years in efforts to separate temporal variability from possible E.L.F. effects.

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## Element 6 - Leaf Litter Processing

Changes from the Original Synopsis - None.

### Objectives

1) To monitor fresh and autumn-abscised leaf processing rates during the fall-winter of 1988; 2) to monitor colonization patterns of insects on fresh and autumn-abscised leaves during the fall-winter of 1987 and, 4) to compare 1987-1988 results with those from prior years.

Processing rates of leaves incorporate the functional responses of fungi, bacteria, other micro-organisms and certain aquatic insects because they use leaves as both a nutritive and substrata resource. Alterations in leaf processing rates and microbial and insect colonization onto leaves in streams have been correlated with a number of perturbation regimes; e.g., chemical (Fairchild et al. 1984, Stout and Cooper 1983, Wilhm and Dorris 1966), thermal stress (Gersick and Brusven 1981), forest cutting practices (Webster and Waide 1982). If E.L.F. alters any of those communities, differences in processing rates of the leaves themselves should be expected. As data thus far show that fresh green and autumn senescent leaves have predictable and consistent leaf processing rates, rate changes as a function of E.L.F. should be detectable.

Insects colonize leaves in a general sequential pattern: After conditioning by bacteria and fungi, insect functional feeding groups such as shredders, scrapers, collector-gatherers, filter-feeders and predators arrive in sequence. If any of those sequence "groups" are missing as a function of E.L.F., not only the sequence pattern, but relative abundances and growth rates of insects on leaves over time can be altered. Changes would be detected via changes in numbers and/or biomasses of functional feeding groups as well as size class structural alterations. Changes in biomass for the functional feeding groups shredders, collector-gatherers and predators (adjusted to changes in leaf mass) were analyzed. In addition, size class changes for three aquatic insect species were determined. Two collector-gatherer mayflies, Ephemera invaria and E. subvaria, and a stonefly predator, Isoperla transmarina were selected as target species as they are common on leafpacks and show changes in size classes over time. A mayfly collector-gatherer Paraleptophlebia mollis was also included to compare its size class changes on leaves with those in the benthos (Element 4).

### Materials and Methods:

#### A. Leaf Processing

On August 28, 1987, fresh tag alder leaves (Alnus rugosa) were collected from a grove adjacent to the Ford

River, weighed into 5.20 to 5.30 gm fresh weight leafpacks and taken to FEX and FCD that day. Autumn abscised leaves from the previous fall were dried for 48 hr at 40°C, weighed into leafpacks ranging in 2.30 to 2.40 gm and taken along with fresh leaf packs to the FEX and FCD sites. Leafpacks for both treatments were lashed to bricks and placed at the sites August 28, 1987. Seven replicates per site were collected after 7, 14, 21, 26, 50 and 76 days. The 1987 Annual Report described leaf processing rates for that study. This Report describes insect colonization patterns on those leaves.

On August 9, 1988, freshly picked tag alder leaves were prepared the same way as for the 1987 study except that leafpacks containing six gms (rather than five gms for prior years) fresh weight of leaves were prepared. The previous year's fall leaves had been dried at 40°C and weighed into three gm leafpacks. Both types of leafpacks were taken to the FEX and FCD sites August 9, lashed to bricks and placed in the river. Leaves were recovered after 7, 14, 21, 28, 41 and 64 days' immersion. This report describes leaf processing rates of the two types of leaves. The next Annual Report will describe the insects on those leaves.

Leaf processing rates ( $-k$ ) were computed after Petersen and Cummins, 1975. Final dry weights for each collection date were used to compute processing rates. Natural Ln values for percent remaining of the leaves were used to compare site and treatment effects for each collection date with 2-Way ANOVA analyses. T-tests were used to compare leaf processing rates among years.

## B. Colonization of Insects on Leaves

The insect taxa from the leaves were determined to the lowest taxon possible except for chironomids. Time constraints disallowed their taxonomic breakdown below family level. Identified insects were then measured to the nearest mm for later computation of biomass values. Species diversity ( $H'$ ), richness ( $S$ ), and evenness ( $J'$ ) were computed for each sample. Numbers of individuals and total biomass for each sample were computed. For select taxa, percent numerical dominance and/or mean biomass per individual were determined. Finally, total biomass values for functional feeding group categories (including a special category, Chironomidae) were computed (after Merritt and Cummins, 1984). Coefficient of variation (C.V.) values for each estimated parameter from each set of samples were computed. A power test was used to determine if sufficient replicates had been collected to have, 95% of the time, confidence that the mean varied no more than  $\pm 40\%$  with an alpha of 0.05. (Seven replicates were sufficient if the parameter had a C.V. value of 20% or less.) If values for any parameter were not normally distributed, they were transformed prior to analysis; e.g., percent data.

## Results and Discussion

### Leaf Processing Rates

1988 Data:

Processing coefficients ( $-k$ ) for fresh leaves were 0.0144 at FEX and 0.0142 at FCD. Coefficients for autumn-abscised leaves were 0.0071 at FEX and 0.0048 at FCD, Figure 6.1. Petersen and Cummins (1974) categorized rates of leaf loss into three categories:  $-k > .010$  = fast;  $.010 > -k > .005$  = intermediate, and  $-k < .005$  = slow. Thus, green tag alder leaves were processed fast and autumn-abscised leaves were processed slowly at FCD and at an intermediate rate at FEX. There were no site differences (fresh leaves,  $T = 0.122$ , d.f. = 82,  $p = 0.451$ ; autumn leaves,  $T = 0.6201$ , d.f. = 82,  $p = 0.268$ ), but there were treatment differences (fresh versus autumn leaves at FEX,  $T = -5.143$ , d.f. = 82,  $p < .00001$ ; fresh versus autumn leaves at FCD,  $T = -4.996$ , d.f. = 82,  $p < .00001$ ).

Table 6.1 shows 2-Way ANOVA values for tests of site versus treatment differences for leaf losses. Treatments (fresh vs. autumn) were significantly different on all collection days. Fresh leaves were processed faster than autumn leaves at both sites. Sites differed significantly only on Day 41. On Day 41, fresh leaves were processed significantly faster at FEX than at FCD; even so, fresh leaves were processed faster than autumn leaves at both sites on that collection date.

TABLE 6.1

Comparisons between Fresh and Autumn-Abscised Leaf Losses, Ln Percent Remaining Dry Mass Values, 1988  
FEX and FCD, 1988. Two-Way ANOVA for Site Versus Treatment

Days in Stream	Source	d.f.	MSS	F-ratio	Prob.
7	site	1	.003	3.166	.088
	treatment	1	.019	22.730	.00007
	interaction	1	.027	33.750	.000005
	error	24	.0008		
14	site	1	.002	1.598	.218
	treatment	1	.343	223.993	<.000001
	interaction	1	.002	1.300	.265
	error	24	.001		
21	site	1	.003	.326	.573
	treatment	1	.206	24.379	.00005
	interaction	1	.015	1.775	.198
	error	16	.008		

FIGURE 6.1

# LEAF MEAN DRY WEIGHTS, FEX AND FCD 1988

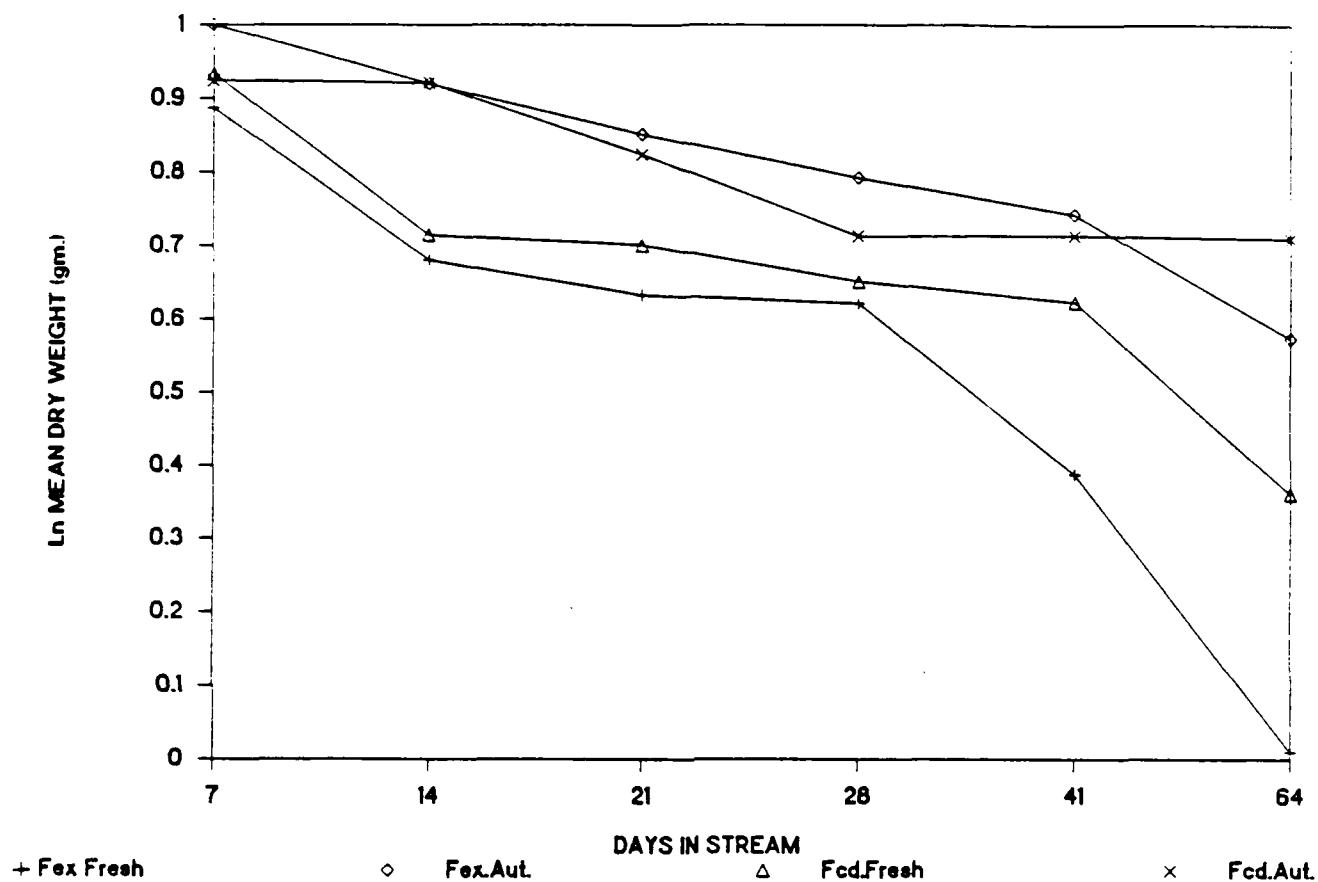


Figure 6.1 1988 Leaf processing for fresh and autumn leaves at FEX and FCD. Processing coefficients, -k: FEX fresh = 0.0144, FEX autumn = 0.0071, FCD fresh = 0.0142, FCD autumn = 0.0048.

Table 6.1, continued

Days in Stream	Source	d.f.	MSS	F-ratio	Prob.
28	site	1	.002	.133	.718
	treatment	1	.167	9.695	.005
	interaction	1	.059	3.471	.075
	error	16	.017		
41	site	1	.075	7.176	.013
	treatment	1	.343	32.963	<.000001
	interaction	1	.123	12.300	.003
	error	24	.010		
64	site	1	.355	.355	.050
	treatment	1	1.257	15.013	.0007
	interaction	1	.111	1.321	.262
	error	24	.084		

## Leaf Decomposition Comparisons Among Years, 1982 - 1987:

Table 6.2 shows  $-k$  values from 1982, through 1988. Fresh leaves were processed significantly faster than were autumn-abscised leaves for the years those treatments were paired at both sites ( $T = 7.742$ , d.f. = 14,  $p = 0.00001$ ).

Table 6.2  
Processing Coefficients ( $-k$ ) For Fresh and Autumn Leaves  
on the Ford River, 1982 to 1988

Season and Year	FEX		FCD	
	Fresh	Autumn	Fresh	Autumn
Fall, Winter, 1982	.0171	.0086	-	-
Fall, Winter, 1984	.0152	.0081	.0150	.0060
Fall, Winter, 1985	.0320	-	.0150	-
Fall, Winter, 1986	.0101	.0034	.0107	.0028
Fall, Winter, 1987	.0115	.0070	.0130	.0049
Fall, Winter, 1988	.0144	.0071	.0142	.0048
MEAN	.0167	.0068	.0136	.0046
S.D.	.0079	.0020	.0018	.0013
N	6	5	5	4

\* site was FS1, 2 km upstream of FEX.



Differences in water temperatures, flow rates, silt deposition and depths differed throughout those years (See Element 1, 1988 Annual Report). Those physical factors can affect processing rates (Fogel and Cromack 1977, Kaushik and Hynes 1971, Suberkropp 1984, Webster and Benfield 1986 and Witcamp 1966). There are site differences between FEX and FCD. Those differences remained consistent from year to year (substrate type, flow rates, and insect functional feeding group patterns). Data presented later in this element and data presented in Element 4 of this Report show that the taxon richness as well as biomass of the insects is greater at FEX than at FCD. The more sandy conditions, higher siltation propensities and lower scouring levels there have remained essentially the same since the data collection began. Thus, relative differences between the two sites with regard to processing rates are consistent and appear to be ascribable to basic physical and biotic differences in the sites. The consistent pattern found in processing rates each year at FEX relative to FCD is powerful. If the relationship switches when E.L.F. activity increases, one could hypothesize that environmental differences between FEX and FCD had less impact on leaf processing than effects of E.L.F. intensities and/or duration.

### Insects Colonizing Leafpacks

#### Structural Community Parameters: 1987 Data

Structural Community Parameters include taxon diversity ( $H'$ ) and evenness ( $J'$ ) after Shannon and Weaver (1963), taxon richness ( $S$ ), chironomid dominance and numbers of individuals.  $H'$  incorporates both  $J'$  and  $S$ . As such, some information is lost if only  $H'$  is presented.  $H'$  and  $J'$  in our analyses are confounded by our identifying chironomids as a family unit rather than to species level. (See species list for taxa identified in substrate samples, Element 4). This was necessary, given time and monetary constraints.

Taxon diversity values for insects on leaves increased from the initial colonization period until Day 26. After Day 26, diversity decreased slowly. This pattern persisted irrespective of site or treatment (Figure 6.2). Diversity values were usually higher on leafpacks at FEX than on leafpacks at FCD for each collection day (Table 6.3).  $H'$  was higher on autumn than on fresh leaves at each site on days 21 and 26.

FIGURE 6.2

# INSECT DIVERSITY ON LEAVES, 1987

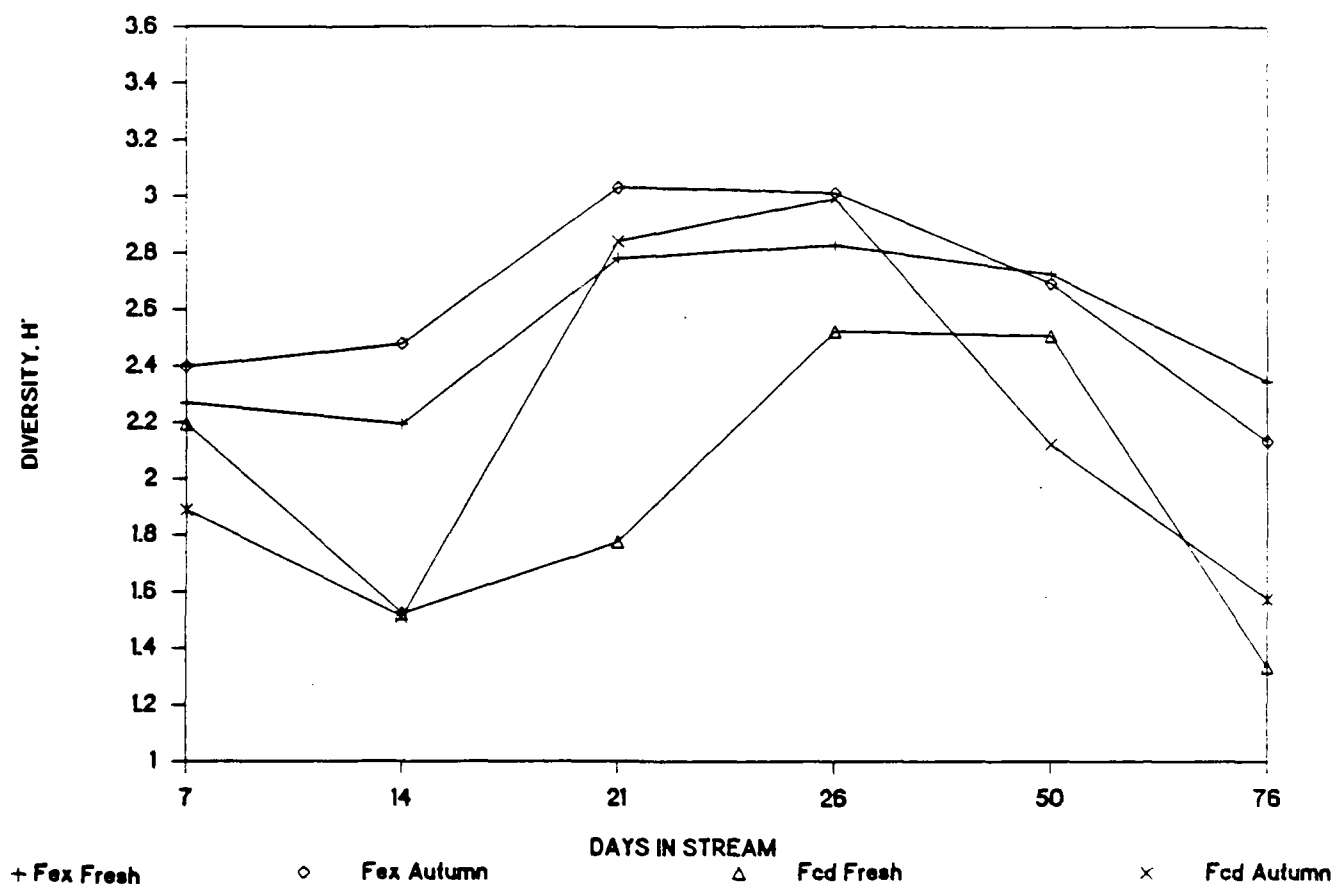


Figure 6.2 1987 taxon diversity values for insects on FEX fresh, FEX autumn, FCD fresh and FCD autumn leaves. (Shannon-Weiner Diversity Index,  $H'$ )

TABLE 6.3  
Comparison of Taxon Diversity Values for Insects on  
Fresh and Autumn Leaves at FEX and FCD, 1987  
Two-Way ANOVA for Site Versus Treatment Differences

Days in Stream	Source	d.f.	MSS	F-ratio	Prob.
7	site	1	.597	13.556	.001
	treatment	1	.054	1.232	.278
	interaction	1	.330	7.500	.011
	error	24	.044		
14	site	1	4.702	60.864	<.000001
	treatment	1	.131	1.698	.205
	interaction	1	.158	2.016	.166
	error	24	.077		
21	site	1	3.902	20.630	.0001
	treatment	1	1.812	9.578	.005
	interaction	1	.469	2.482	.1283
	error	24	.189		
26	site	1	.182	2.947	.099
	treatment	1	.746	12.064	.002
	interaction	1	.142	2.290	.143
	error	24	.062		
50	site	1	1.094	14.271	.0009
	treatment	1	.306	3.991	.057
	interaction	1	.217	2.818	.106
	error	24	.077		
76	site	1	4.318	72.435	<.000001
	treatment	1	.001	.024	.878
	interaction	1	.360	6.000	.022
	error	24	.060		

Unlike the diversity index, taxon richness steadily increased on both types of leaves at the sites until Day 50. After that time, there was a slight decrease (Figure 6.3). Taxon richness was higher on leafpacks at FEX as contrasted with FCD. Element 4 of this Report shows that taxon richness was also higher for the insects in the substrates at FEX. There were site but no treatment differences for S after Day 7, Table 6.4. Thus, leaves at FEX irrespective of whether or not they were fresh or autumn-abscised contained more taxa than did leaves at FCD.

FIGURE 6.3

# INSECT RICHNESS ON LEAVES, 1987

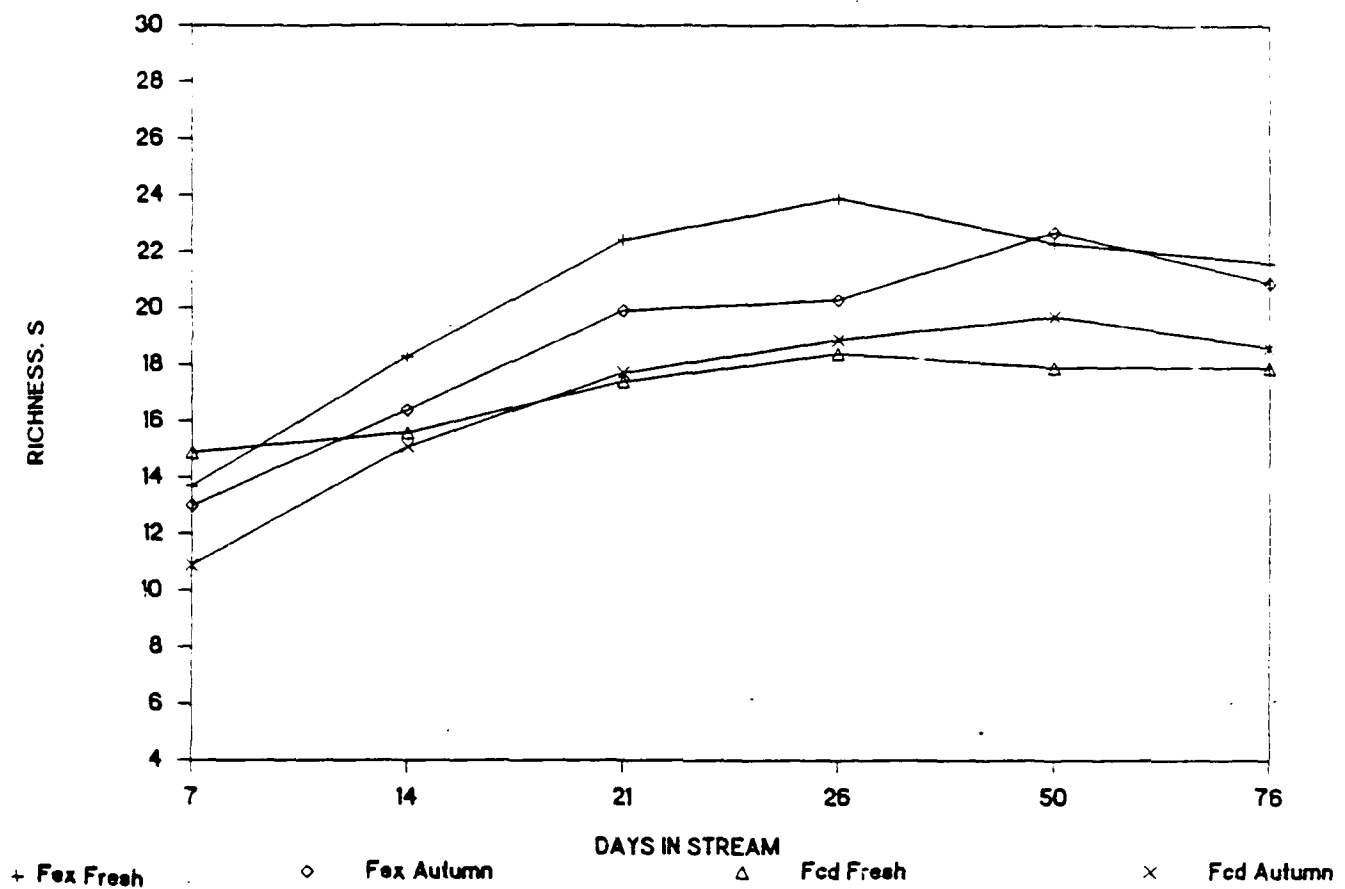


Figure 6.3 1987 taxon richness for insects on fresh and autumn leaves at FEX and FCD sites.

FIGURE 6.4

# INSECT EVENNESS ON LEAVES, 1987

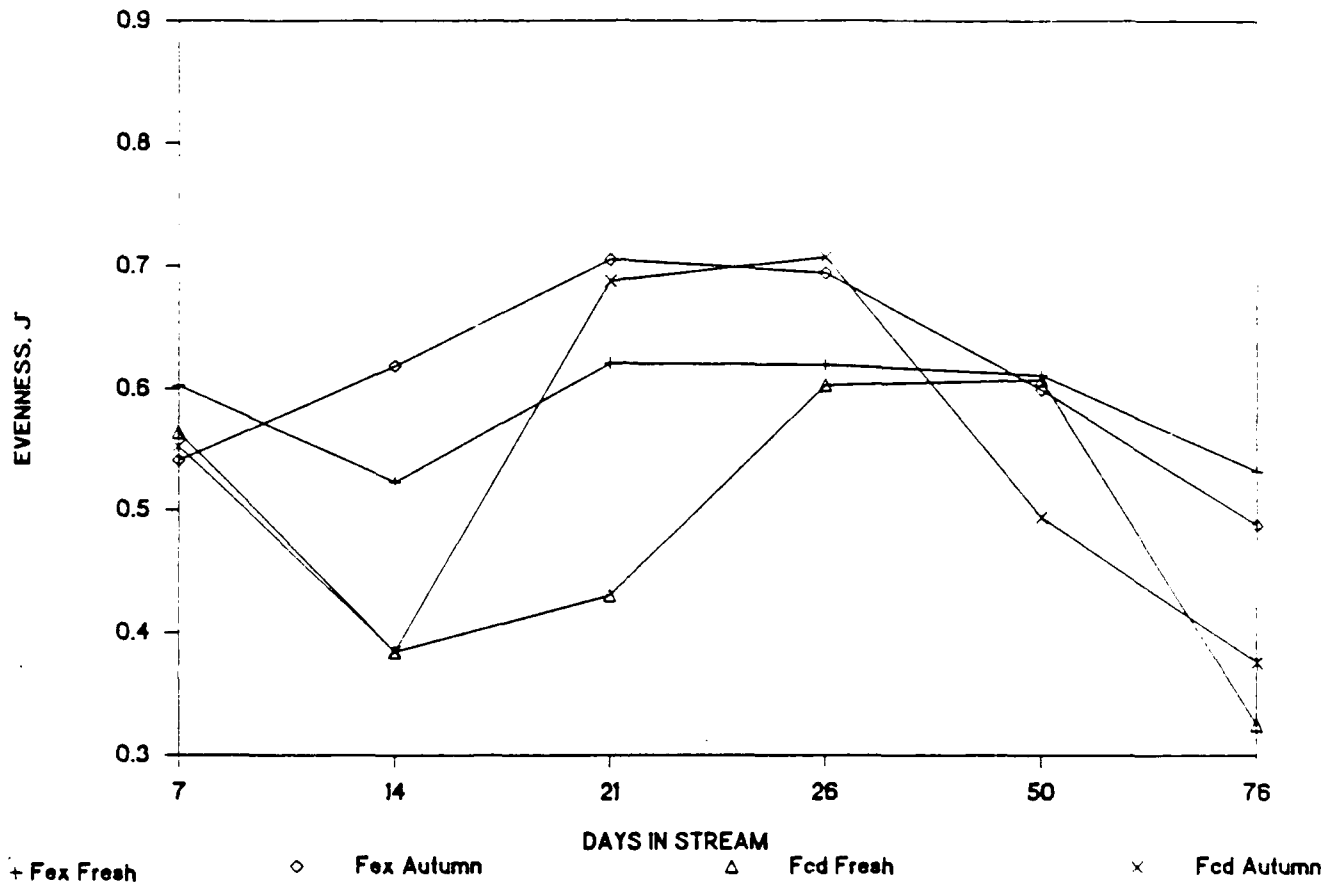


Figure 6.4 1987 taxon evenness values for insects on FEX fresh, FEX autumn, FCD fresh and FCD autumn leaves. (Shannon-Weiner Diversity Index,  $J'$ )

TABLE 6.4  
Comparisons Among Taxon Richness Values (S) for Insects  
on Fresh and Autumn Leaves at FEX and FCD, 1987  
Two-Way ANOVA for Site Versus Treatment Differences

Days in Stream	Source	d.f.	MSS	F-ratio	Prob.
7	site	1	1.750	.626	.437
	treatment	1	38.893	13.902	.001
	interaction	1	18.893	6.752	.016
	error	24	2.798		
14	site	1	28.000	6.125	.021
	treatment	1	9.143	2.000	.170
	interaction	1	3.571	.781	.386
	error	24	4.571		
21	site	1	89.286	20.270	.0001
	treatment	1	9.143	2.076	.163
	interaction	1	14.286	3.243	.084
	error	24	4.405		
26	site	1	82.286	16.340	.0005
	treatment	1	17.286	3.433	.076
	interaction	1	28.000	5.560	.027
	error	24	5.036		
50	site	1	96.571	15.134	.0007
	treatment	1	9.143	1.433	.243
	interaction	1	3.571	.560	.462
	error	24	6.381		
76	site	1	63.000	5.790	.024
	treatment	1	.000	.000	1.000
	interaction	1	3.571	.328	.572
	error	24	10.887		

Maximum evenness values ( $J'$ ) occurred on days 21 and 26. (Figure 6.4). During that time, evenness was highest on autumn leaves at both sites. 2-Way ANOVA tests show that generally there were site differences for each collection date. Cell means show that  $J'$  was higher on leaves at FEX than on leaves at FCD except for days 21 and 26. For those days, insects on autumn leaves had higher  $J'$  values than insects on fresh leaves (Table 6.5). Table 6.3 showed the same result for  $H'$ .

TABLE 6.5  
Comparison of Evenness Values for Insects on Fresh and Autumn  
Leaves at FEX and FCD, 1987 (Arcsine Transform)  
Two-Way ANOVA for Site Versus Treatment Differences

Days in Stream	Source	d.f.	MSS	F-ratio	Prob.
7	site	1	111.361	12.367	.002
	treatment	1	8.691	.965	.336
	interaction	1	22.072	2.451	.130
	error	24	9.004		
14	site	1	655.626	31.990	.000008
	treatment	1	18.000	.878	.358
	interaction	1	18.484	.902	.352
	error	24	20.495		
21	site	1	432.457	14.133	.001
	treatment	1	486.222	15.890	.0005
	interaction	1	64.630	2.112	.159
	error	24	30.599		
26	site	1	.042	.005	.946
	treatment	1	209.118	23.059	.00007
	interaction	1	5.779	0.637	.433
	error	24	9.069		
50	site	1	70.184	4.813	.038
	treatment	1	94.539	6.483	.018
	interaction	1	57.802	3.964	.058
	error	24	14.583		
76	site	1	614.016	52.074	<.000001
	treatment	1	.554	.047	.8302
	interaction	1	56.857	4.822	.038
	error	24	11.791		

The chironomid dominance pattern was sinesoid, with a peak at Day 14, then a drop until Day 50 where dominance increased until the end of the study. The pattern was consistent at both sites and for both treatments (Figure 6.5). Table 6.6 shows that there were site and treatment differences for chironomid dominance. Chironomid dominance usually was high on leaves at FCD (days 7, 14, 21, 50 and 76). That site contains more sand than does the FEX site and there is more deposition of leaf material in the shifting sands than at the FEX site where more erosion takes place. This difference may contribute to the higher numbers of chironomids at FCD, both on the leafpacks and in the substrate samples (Element 4).

FIGURE 6.5

# CHIRONOMID DOMINANCE ON LEAVES, 1988

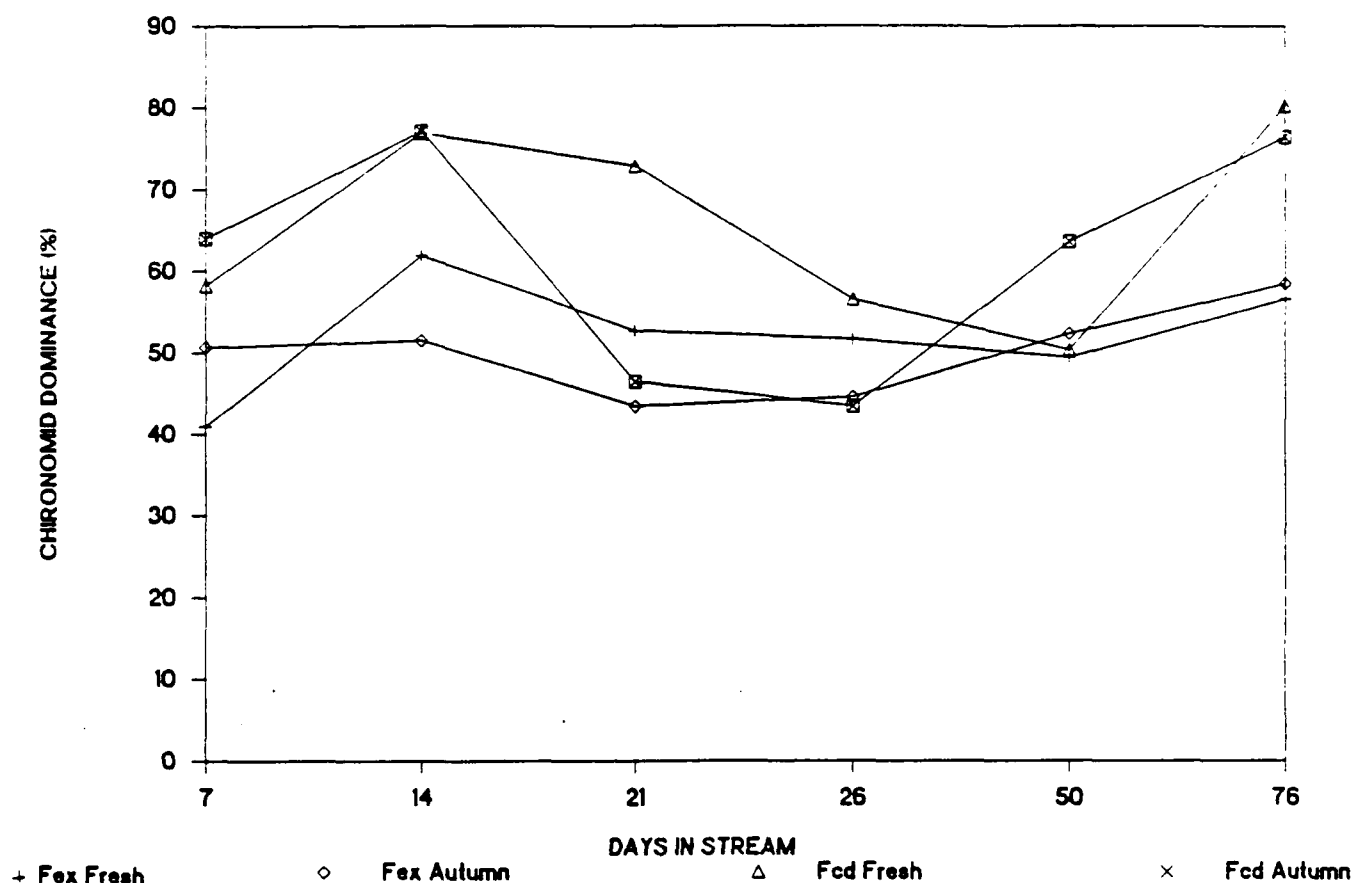


Figure 6.5 1987 chironomid dominance values (number of chironomids/total number of all insects) for insects on FEX fresh, FEX autumn, FEX fresh and FCD autumn leaves.



TABLE 6.6

Comparisons Among Numerical Dominance Values for  
Chironomids on Fresh and Autumn Leaves at FEX and FCD, 1987  
Two-Way ANOVA for Site Versus Treatment Differences  
(Arcsine Transformation)

Days in Stream	Source	d.f.	MSS	F-ratio	Prob.
7	site	1	558.036	33.739	.000005
	treatment	1	140.403	8.489	.008
	interaction	1	9.052	.547	.467
	error	24	16.540		
14	site	1	1116.997	58.080	<.000001
	treatment	1	59.948	3.117	.090
	interaction	1	69.363	3.607	.070
	error	24	19.232		
21	site	1	334.721	57.715	<.000001
	treatment	1	781.757	134.797	<.000001
	interaction	1	189.748	32.721	.000007
	error	24	5.799		
26	site	1	8.251	.610	.442
	treatment	1	238.389	17.623	.0003
	interaction	1	22.752	1.682	.207
	error	24	13.527		
50	site	1	91.116	4.393	.047
	treatment	1	157.4155	7.589	.011
	interaction	1	63.210	3.047	.094
	error	24	20.743		
76	site	1	1176.768	70.200	<.000001
	treatment	1	4.512	.269	.609
	interaction	1	23.114	1.379	.252
	error	24	16.763		

As for chironomid dominance patterns on leaves, the curve for mean number of individuals was sinesoidal (Figure 6.6). After an increase on Day 14, numbers of individuals remained essentially the same until Day 26. After that, numbers increased again. The richness (S) values were stable during this latter period, and most of the increase in numbers came from chironomids rather than from additional species. Thus, the drop in H' and J' on the leaves as the leaves became more than 50% processed was more attributable to the increase in chironomids on those decomposing leaves. Table 6.7 shows that there were more insects on fresh than on autumn leaves on days 7 through 26, the time of initial colonization (Figure 6.6).

FIGURE 6.6

# MEAN NO. INSECTS ON LEAVES, 1987

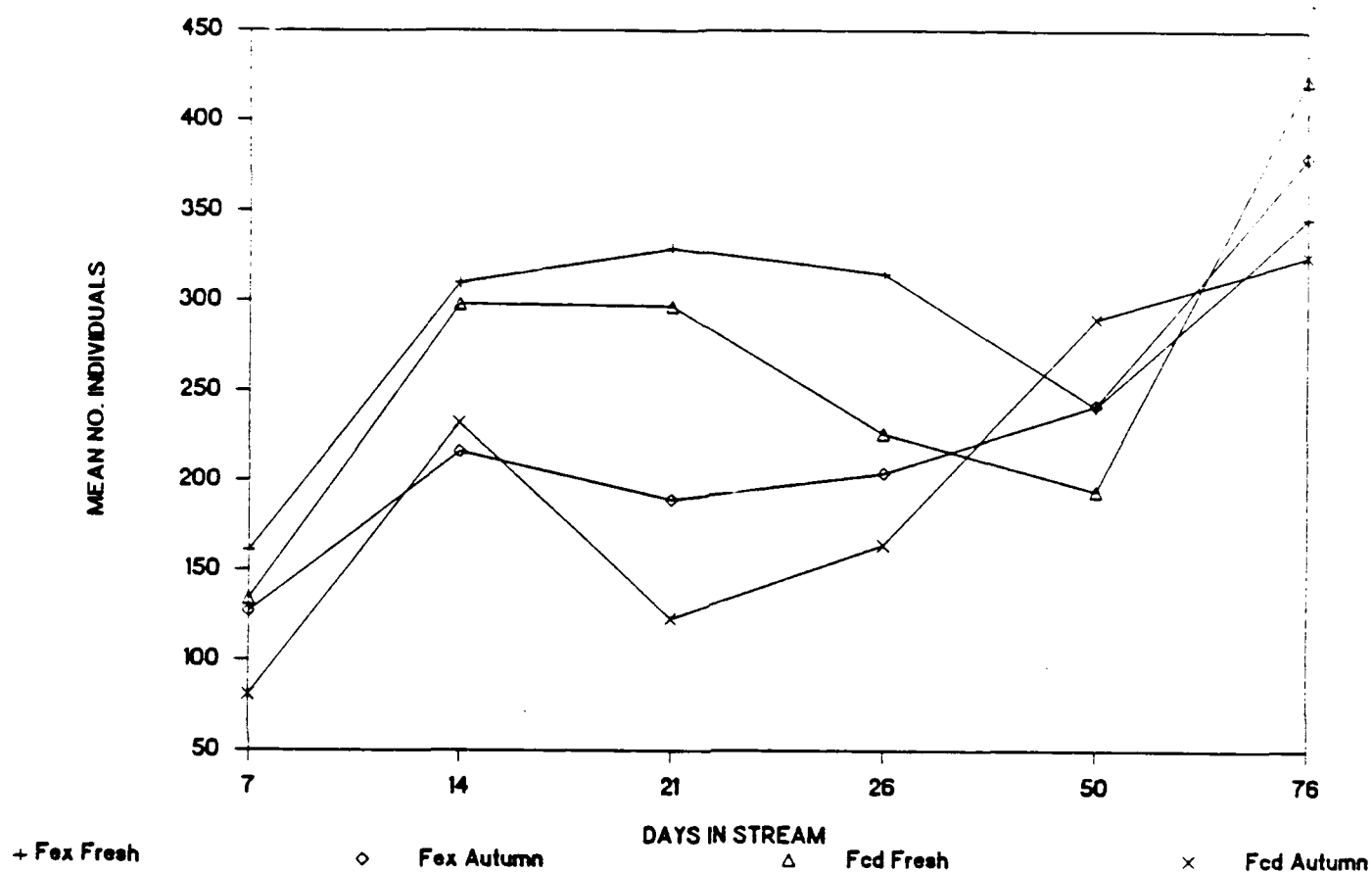


Figure 6.6 1987 mean numbers of insects found on fresh and autumn leaves at FEX and FCD sites.

TABLE 6.7  
Comparisons Among Numbers of Individuals on Fresh and Autumn  
Leaves at FEX and FCD, 1987  
Two-Way ANOVA for Site Versus Treatment Differences

Days in Stream	Source	d.f.	MSS	F-ratio	Prob.
7	site	1	9252.893	14.462	.0009
	treatment	1	13158.893	20.567	.0001
	interaction	1	594.321	.929	.345
	error	24	639.798		
14	site	1	22.321	.007	.931
	treatment	1	44560.321	15.375	.0006
	interaction	1	1358.036	4.4695	.500
	error	24	2898.274		
21	site	1	3703.000	3.394	.078
	treatment	1	121177.286	111.074	<.000001
	interaction	1	567.000	.520	.478
	error	24	1090.964		
26	site	1	21506.286	8.676	.007
	treatment	1	42276.571	17.055	.0004
	interaction	1	7557.143	3.049	.094
	error	24	2478.869		
50	site	1	.036	.000	.998
	treatment	1	16272.321	3.134	.089
	interaction	1	15793.750	3.041	.094
	error	24	5192.881		
76	site	1	880.321	.062	.805
	treatment	1	6945.750	.491	.490
	interaction	1	30690.321	2.168	.154
	error	24	14153.940		

The lowest variance to mean ratios for the structural community parameters occurred at Day 26 (figs. 6.7 A, B, C and D). During the initial colonization phase, coefficient of variation (C.V.) values fluctuated for sites and treatments, an expected finding for that very dynamic phase. Near the end of the first month's colonization period when leaves had been conditioned by micro-organisms and the leaves were still relatively intact, C.V. values were low and were also similar for site and treatment variables. From Day 50 onward, during the time when most of the leafpacks had lost at least 50% of their original mass, C.V. values again fluctuated for site and treatment.

FIGURE 6.7A

# C.V. VALUES, DIVERSITY ON LEAVES, 1987

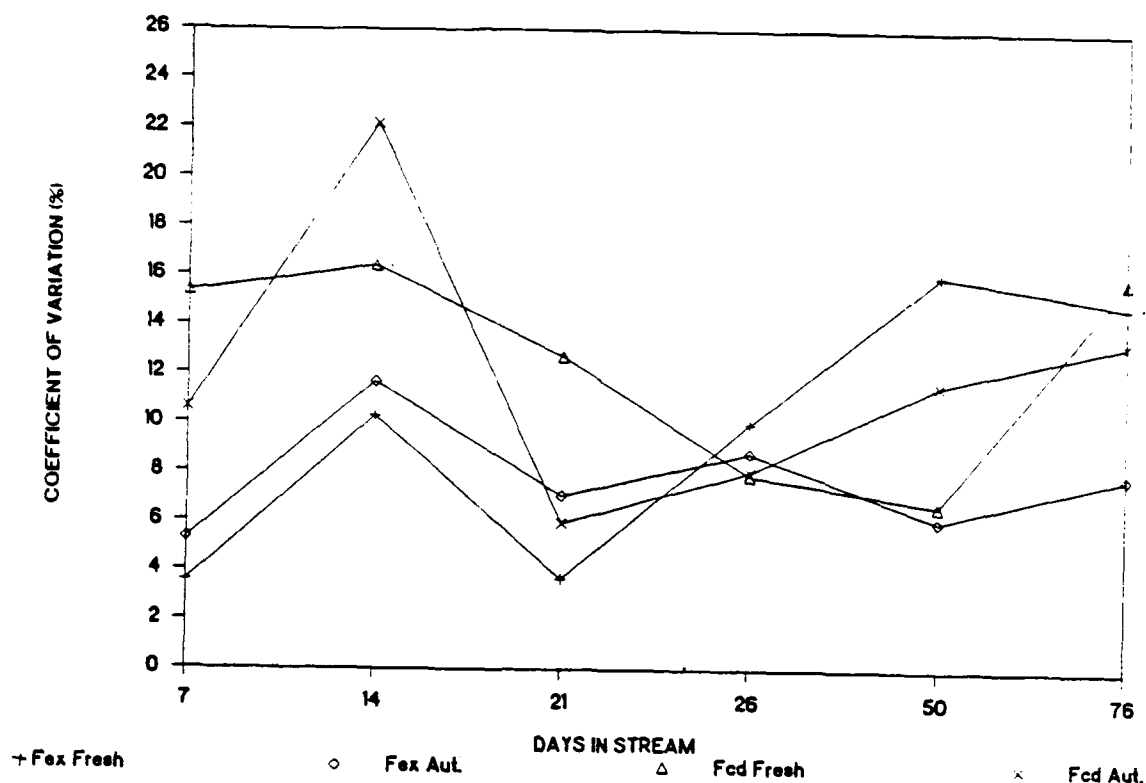


FIGURE 6.7B

# C.V. VALUES, RICHNESS ON LEAVES, 1987

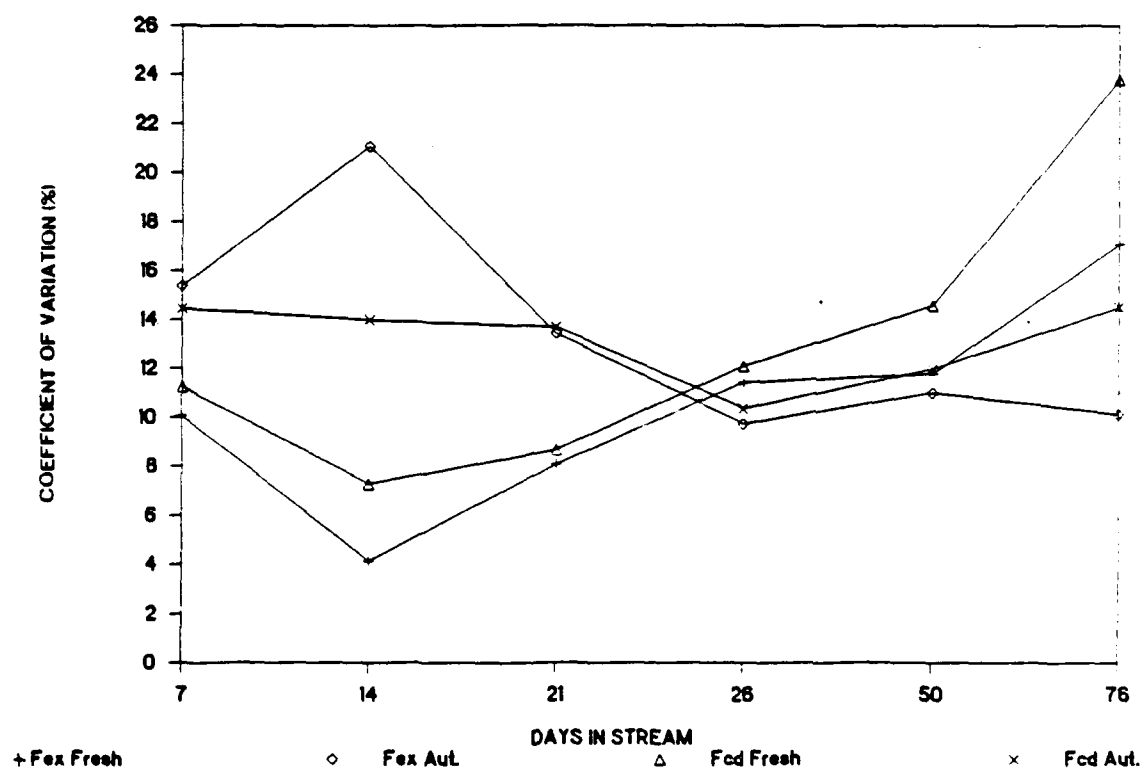


Figure 6.7A. Coefficient of variation values for Taxon Diversity on fresh and autumn leaves at FEX and FCD sites.  
 Figure 6.7B. Coefficient of variation values for Taxon Richness on fresh and autumn leaves at FEX and FCD sites.

FIGURE 6.7C

# C.V. VALUES. EVENNESS ON LEAVES, 1987

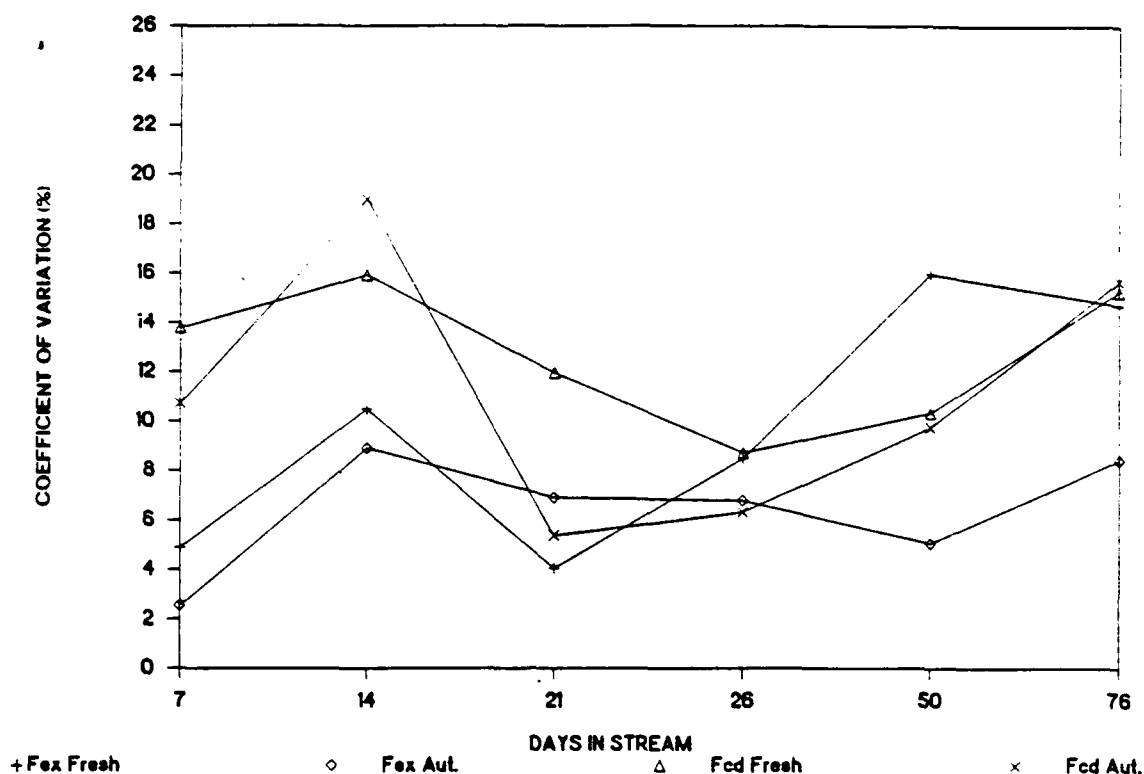


FIGURE 6.7D

# C.V. VALUES. NO. INDIV. ON LEAVES, 1987

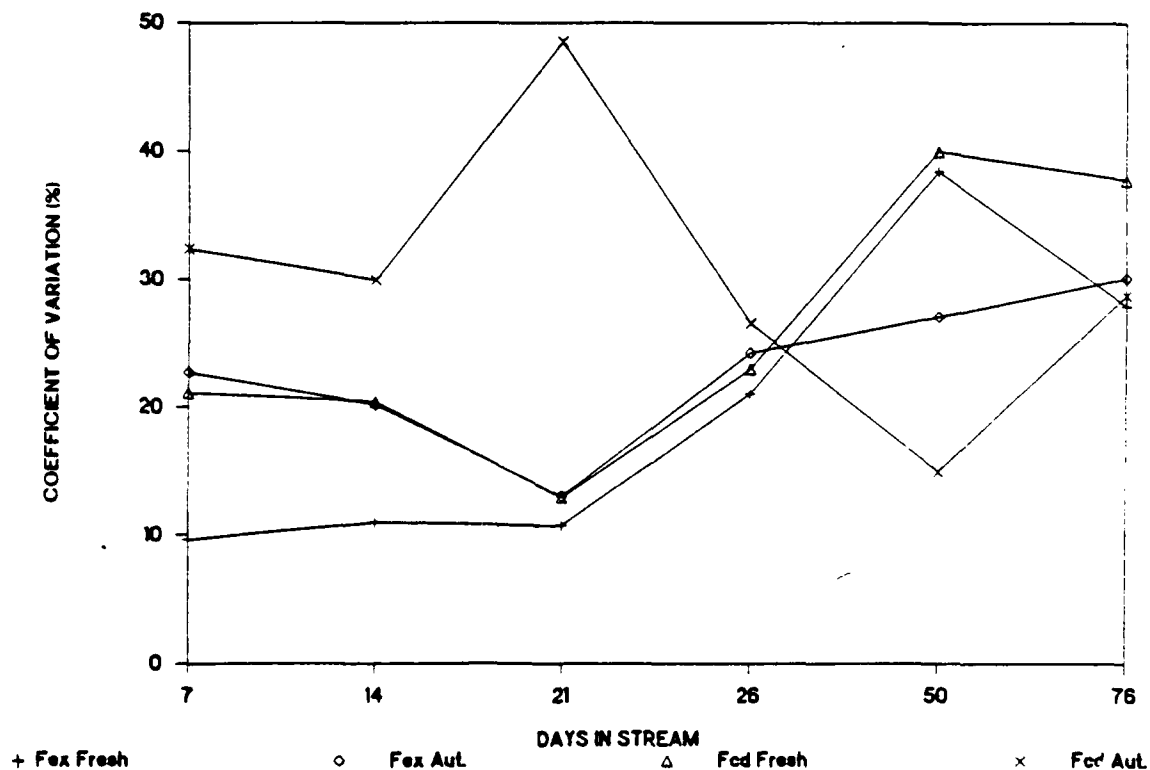


Figure 6.7C. Coefficient of variation values for Taxon Evenness on fresh and autumn leaves at FEX and FCD sites.

Figure 6.7D. Coefficient of variation values for Numbers of Insects on fresh and autumn leaves at FEX and FCD sites.

# Comparisons, 1982 - 1987

The patterns for diversity (H') and evenness (J') were similar in 1982, 1984 and 1987 with an increase during the first month and thereafter a decrease in the indices. In 1985 and 1986 the decrease occurred after the first 9 days. Taxon richness (S) peaked by the end of a month and then diminished for all the years except for 1982. In 1982, numbers of taxa decreased steadily over time. The site for the 1982 study differed from the other studies. Final designation of the ELF lines occurred in 1983, and the 1982 site was deleted in favor of the FEX site adjacent to the planned location of the lines. Although the 1982 site was only km upstream from the FEX site, slight physical differences between the two sites may have had an effect on some biotic parameters. Mean numbers of individuals peaked at three weeks of leaf incubation for all years we conducted the studies. The repeated increase in numbers of individuals on leafpacks each year was related to an increase in chironomids. Percent dominance of chironomids increased over time each year except for a slight depression after three week's incubation of the leaves.

Coefficient of variation (C. V.) values were graphed for H', S, J', number of individuals and chironomid dominance on leaves in 1982, and 1984 through 1987. (Graphs are available on request.) As for 1987, the lowest and most similar C.V. values occurred at the end of the first month's incubation of leaves. s that period in the study showed the lowest variance relative to the mean, there is more confidence that the estimated mean for the parameters in question is close to the true mean. Table 6.8 gives means for those parameters after 24 to 27 days' incubation of leaves in 1982 through 1987 (excluding 1983 when the studies were not done).

TABLE 6.8

Means for Diversity (H'), Richness (S), Evenness (J'),  
Numbers of Individuals and Chironomid Dominance after 24 to 27  
Days on Fresh and Autumn Leaves at FS1, FEX and FCD  
Years 1982, 1984, 1985, 1986 and 1987

YEAR, (DAY)	SITE	TREATMENT	H'	S	J'	NO. INDIV	CHIRO DOM (%)
1982	FS1*	Fresh	2.032	19	.479	657	63.76
22 Sept.		Autumn	1.952	13	.526	127	62.78
24 days							
1984	FEX	Fresh	3.021	15	.769	138	36.22
19 Oct.		Autumn	3.231	17	.794	123	28.42
	FCD	Fresh	3.188	19	.755	148	28.79
27 days		Autumn	2.980	14	.784	86	19.48

Table 6.8, continued

YEAR, (DAY)	SITE	TREATMENT	H'	S	J'	NO. INDIV.	CHIRO DOM. (%)
1985	FEX	Fresh	2.538	17	.631	177	51.21
13 Oct.		Dried	3.078	16	.769	106	36.56
	FCD	Fresh	3.106	14	.675	71	41.63
27 days		Dried	2.525	12	.699	66	41.99
1986	FEX	Fresh	2.553	17	.586	242	47.94
7 Oct.		Autumn	3.274	29	.680	336	39.85
	FCD	Fresh	2.514	21	.518	302	50.17
27 days		Autumn	2.842	29	.586	321	53.43
1987	FEX	Fresh	2.828	24	.619	315	51.71
23 Sept.		Autumn	3.012	20	.694	204	44.60
	FCD	Fresh	2.524	18	.602	226	56.69
26 days		Autumn	2.993	19	.707	167	43.43

There is no pattern for H' versus treatment, but H' is usually higher at FEX than at FCD over the years. Richness is usually higher on fresh than autumn leaves and S' is usually higher at FEX than at FCD. J' usually was higher at FEX than at FCD. It was always higher on autumn than on fresh leaves, which suggests that there are preferences by individuals of certain species for fresh leaves. No distinctive comparison occurred for chironomid dominance by the fourth week. There usually were more individuals on fresh than on autumn leaves, and more individuals were found on fresh or autumn leaves at FEX than on fresh or autumn leaves at FCD. In summary, leaves at the FEX site usually contained a more diverse and more equitable insect community as well as more individuals and more taxa than did leaves at FCD over the years after the leaves had been incubated at the sites for nearly four weeks. When more operational data for E.L.F. (1987 and beyond), before and after statistical comparisons will be made for these parameters after 24 to 28 days' incubation.

#### Functional Community Parameters

##### 1987 Data:

Total biomass values (adjusted to leaf biomass) showed a consistent upward trend over time (figs. 6.8A, 6.8B). This was also true for total biomass values unadjusted to leaf biomass over time. A 2-Way ANOVA showed treatment differences throughout the study, with fresh leaves supporting a higher mean biomass of insects than autumn leaves at each site (Table

FIGURE 6.8A

## TOTAL BIOMASS, FRESH LEAVES 1987

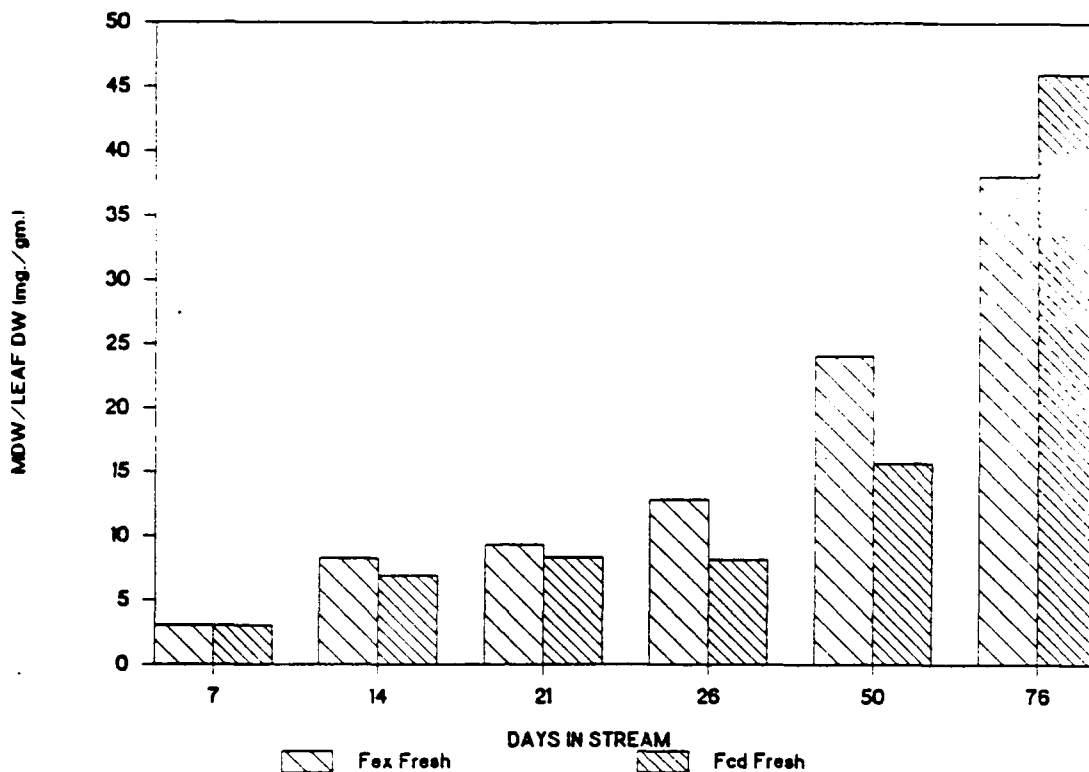


FIGURE 6.8B

## TOTAL BIOMASS, AUTUMN LEAVES 1987

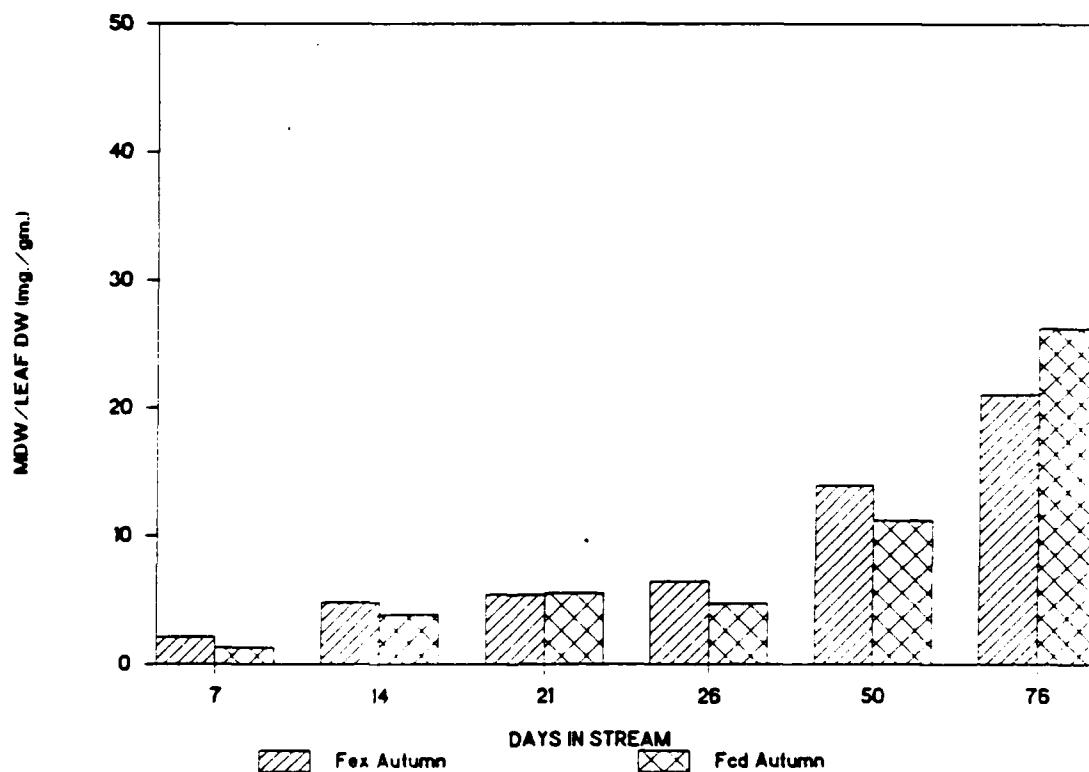


Figure 6.8A. Total biomass of insects (adjusted to leaf mass) on fresh for FEX and FCD sites, 1987.

Figure 6.8B. Total biomass of insects (adjusted to leaf mass) on autumn leaves for FEX and FCD sites, 1987.



6.9). There were site differences only once, Day 26, when there were higher values at FEX than at FCD. Coefficient of variation values for this parameter were moderate (C.V. mean = 27.39% s.d. = 9.56 n = 24).

Coefficient of variation values were lowest on Day 21 for leaf biomass (8.17%), total insect biomass (21.16%) and total insect biomass/leaf biomass (20.73%). Again, as for structural community parameters, the least variation occurred after the initial colonization phase and before leaves lost over 50% of their mass. The period where one is most confident that the true mean is  $\pm 40\%$  of statistical mean at the 0.05 probability level is a the mid-phase of the study.

TABLE 6.9

Comparisons of Total Insect Biomass (Adjusted to Leaf Biomass)  
Between Fresh and Autumn Leaves at FEX and FCD, 1987  
Two-Way ANOVA for Site Versus Treatment Differences

Days in Stream	Source	d.f.	MSS	F-ratio	Prob.
7	site	1	1.169	2.253	.146
	treatment	1	12.539	24.163	.00005
	interaction	1	1.181	2.276	.144
	error	24	.519		
14	site	1	8.969	3.156	.088
	treatment	1	74.500	26.215	.00003
	interaction	1	.279	.098	.757
	error	24	2.842		
21	site	1	1.180	.443	.512
	treatment	1	78.392	29.427	.00001
	interaction	1	2.061	.774	.388
	error	24	2.664		
26	site	1	50.408	6.700	.016
	treatment	1	206.649	27.468	.00002
	interaction	1	28.119	3.738	.065
	error	24	7.523		
50	site	1	55.557	4.132	.053
	treatment	1	144.194	10.723	.003
	interaction	1	.045	.003	.954
	error	24	13.447		
76	site	1	20.108	.167	.686
	treatment	1	351.174	2.919	.100
	interaction	1	3967.241	32.980	.000006

FIGURE 6.9A

# COLLECTORS, FRESH LEAVES 1987

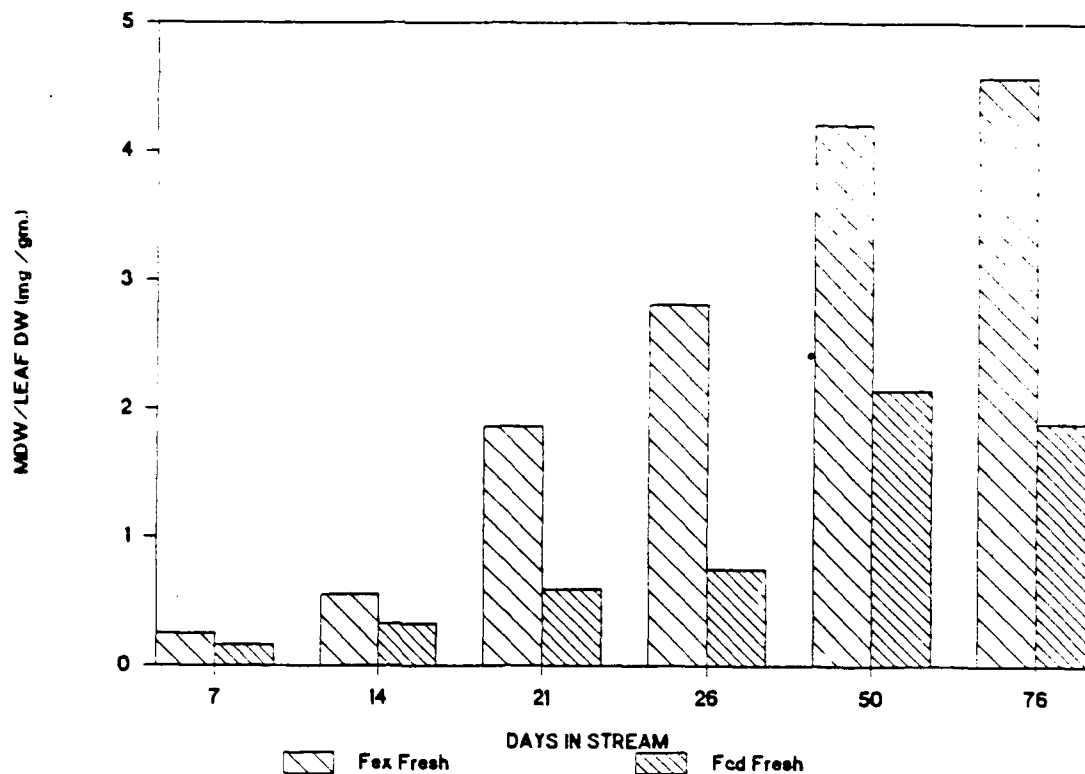


FIGURE 6.9B

# COLLECTORS, AUTUMN LEAVES 1987

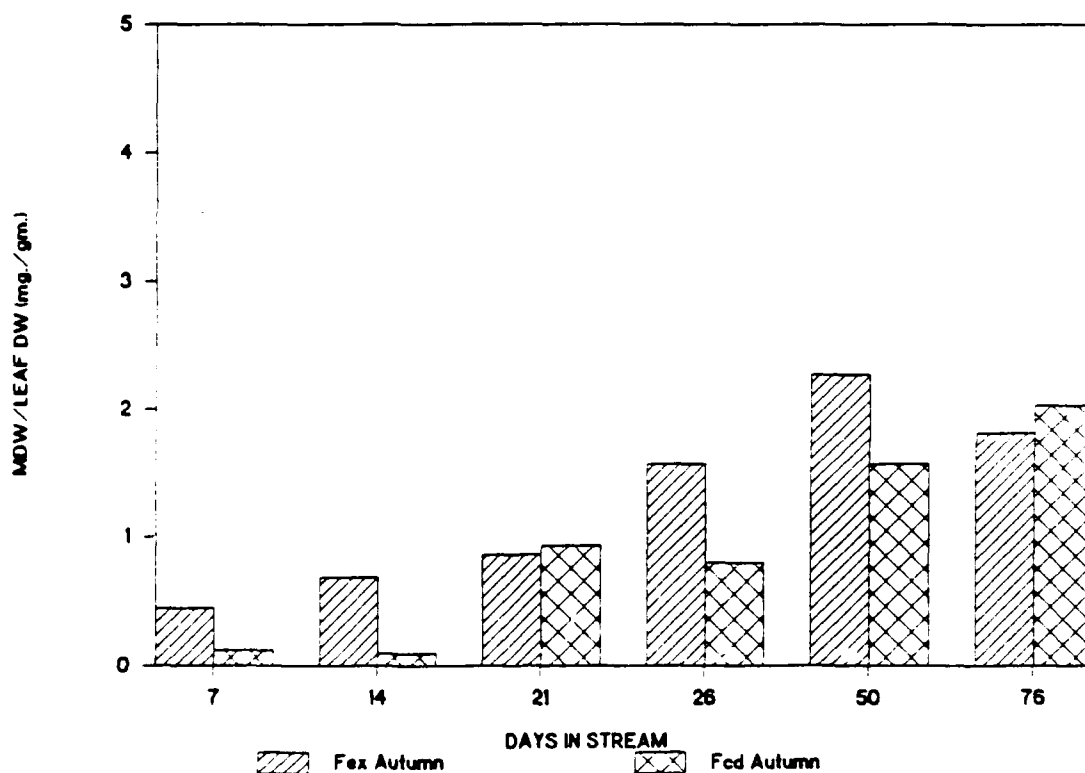


Figure 6.9A. Biomass of collectors (adjusted to leaf mass) on fresh leaves for FEX and FCD sites, 1987.

Figure 6.9B. Biomass of collectors (adjusted to leaf mass) on autumn leaves for FEX and FCD sites, 1987.

Collector-gatherer biomass continued to increase on fresh leaves over time (Figure 6.9 A, B). The highest biomass values were consistently found on fresh leaves at FEX. Collector-gatherer biomass values were lower on autumn leaves, but autumn leaves at FEX attracted higher masses than autumn leaves at FCD.

Table 6.10 shows that there were site and treatment differences after Day 14. This occurred because insects on fresh leaves at FCD never approached the biomass of insects on fresh leaves at FEX. In fact, fresh leaves at FCD supported about the same collector-gatherer biomass as autumn leaves at either site (Figure 6.9 A, B).

TABLE 6.10

Comparisons of Collector-Gatherer Biomass (Adjusted to Leaf Biomass) Between Fresh and Autumn Leaves at FEX and FCD, 1987  
Two-Way ANOVA for Site Versus Treatment Differences

Days in Stream	Source	d.f.	MSS	F-ratio	Prob.
7	site	1	.301	8.916	.006
	treatment	1	.043	1.267	.272
	interaction	1	.098	2.882	.102
	error	24	.034		
14	site	1	1.177	19.076	.0002
	treatment	1	.017	.271	.607
	interaction	1	.234	3.774	.063
	error	24	.062		
21	site	1	4.651	25.483	.00004
	treatment	1	2.093	11.466	.002
	interaction	1	1.430	7.814	.01
	error	24	.183		
26	site	1	14.013	38.688	<.00001
	treatment	1	2.485	6.862	.015
	interaction	1	2.925	8.010	.009
	error	24	.365		
50	site	1	13.414	9.910	.004
	treatment	1	11.081	8.186	.009
	interaction	1	3.297	2.435	.132
	error	24	1.354		
76	site	1	10.742	7.129	.013
	treatment	1	12.083	8.020	.009
	interaction	1	14.835	9.844	.004
	error	24	1.507		

FIGURE 6.10A

## SHREDDERS. FRESH LEAVES 1987

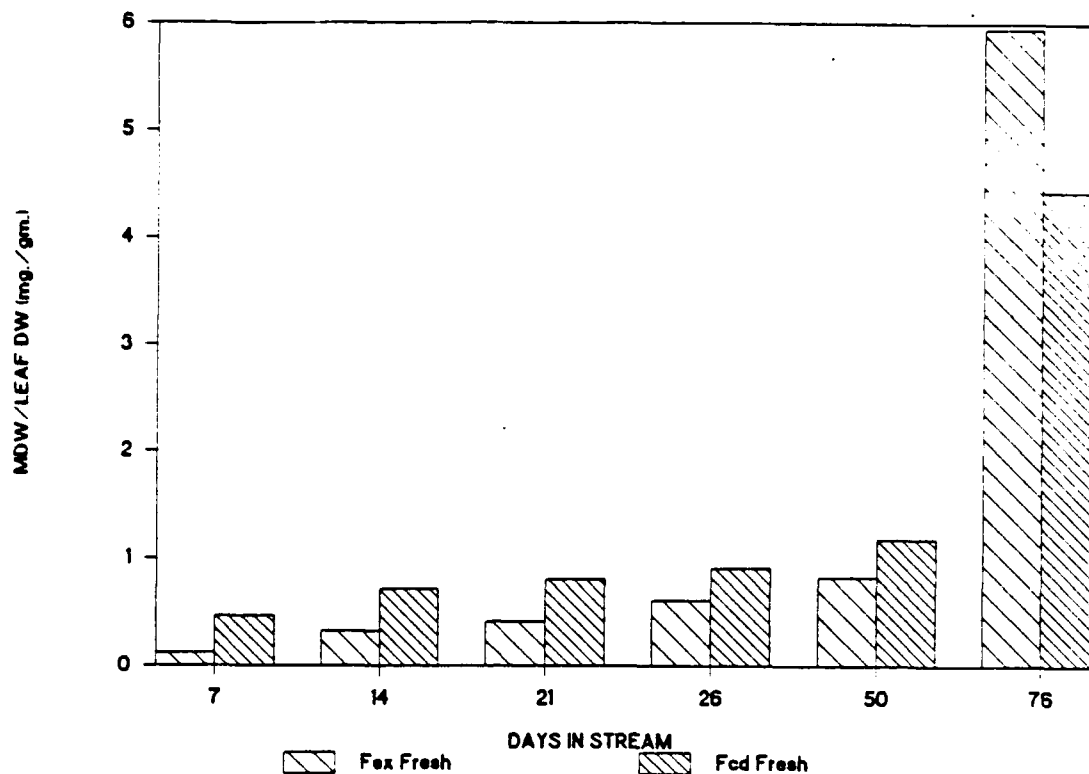


FIGURE 6.10B

## SHREDDERS. AUTUMN LEAVES 1987

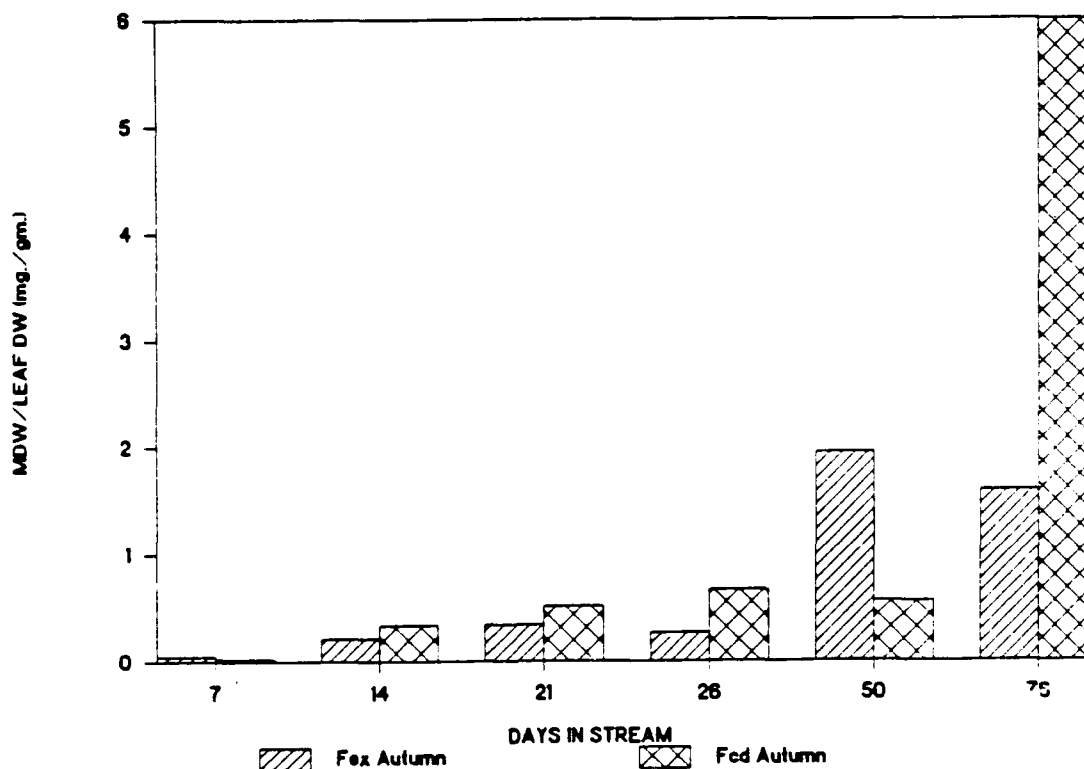


Figure 6.10A. Biomass of shredders (adjusted to leaf mass) on fresh leaves for FEX and FCD sites, 1987.

Figure 6.10B. Biomass of shredders (adjusted to leaf mass) on autumn leaves for FEX and FCD sites, 1987.

Shredder biomass, adjusted to leaf biomass, values were consistently low, except for the last collection date when most of the leaf mass had already been processed (Figure 6.10 A, B). There were no treatment or site differences for shredder biomass values after Day 7. For that reason 2-Way ANOVA analyses are not presented in this Report.

Predator biomass values, adjusted to leaf biomass, were higher on fresh than on autumn leaves by Day 21 (Figures 6.11 A, B). 2-Way ANOVA tests showed that treatment differences occurred on days 21, 26 and 50 (Table 6.11). It could be that predators were attracted to the higher mass of prey on fresh leaves during that period (See Figures 6.8 A, B).

TABLE 6.11

Comparisons of Predator Biomass (Adjusted to Leaf Biomass)  
Between Fresh and Autumn Leaves at FEX and FCD, 1987  
Two-Way ANOVA for Site Versus Treatment Differences

Days in Stream	Source	d.f.	MSS	F-ratio	Prob.
21	site	1	.425	2.224	.149
	treatment	1	.943	4.941	.036
	interaction	1	.472	2.471	.129
	error	24	.191		
26	site	1	.078	.533	.472
	treatment	1	1.346	9.192	.006
	interaction	1	.082	.562	.462
	error	24	.146		
50	site	1	1.272	5.514	.027
	treatment	1	1.016	4.402	.047
	interaction	1	.524	2.268	.145
	error	24	.231		

Insect biomass values according to functional feeding groups incorporate many species. For this reason, individual species from the collector-gatherer and predator functional feeding groups were analyzed separately. Size class changes for three collector-gatherers, the mayflies Ephemera invaria, E. subvaria, and Paraleptophlebia mollis, and the stonefly predator Isoperla transmarina were followed using mean dry weight per individual values (MDW/IND).

The MDW/IND of Ephemera invaria increased over time after Day 21 on both fresh and autumn leafpacks (Fig. 6.12A). Prior to Day 21, C.V. values were very high for this species (mean C.V. for days 7 and 14 = 48% n = 8). They decreased during the remaining 62 days (mean C.V. = 25%, n = 14). A

FIGURE 6.11A

# PREDATORS, FRESH LEAVES 1987

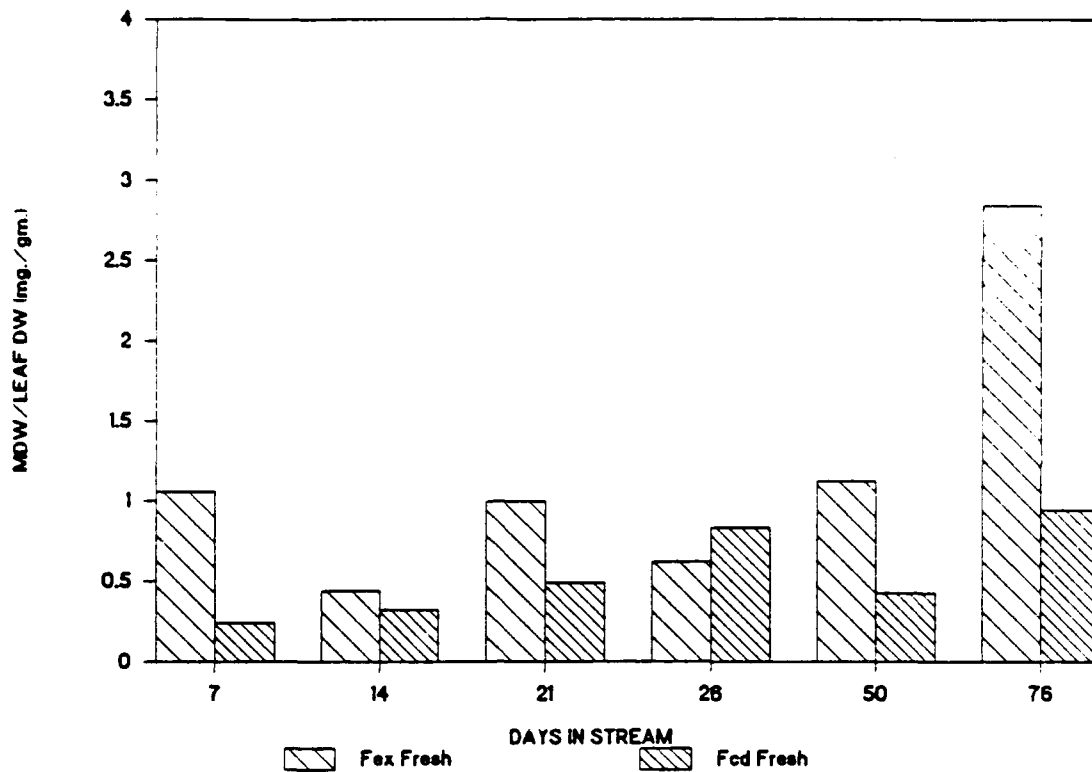


FIGURE 6.11B

# PREDATORS, AUTUMN LEAVES 1987

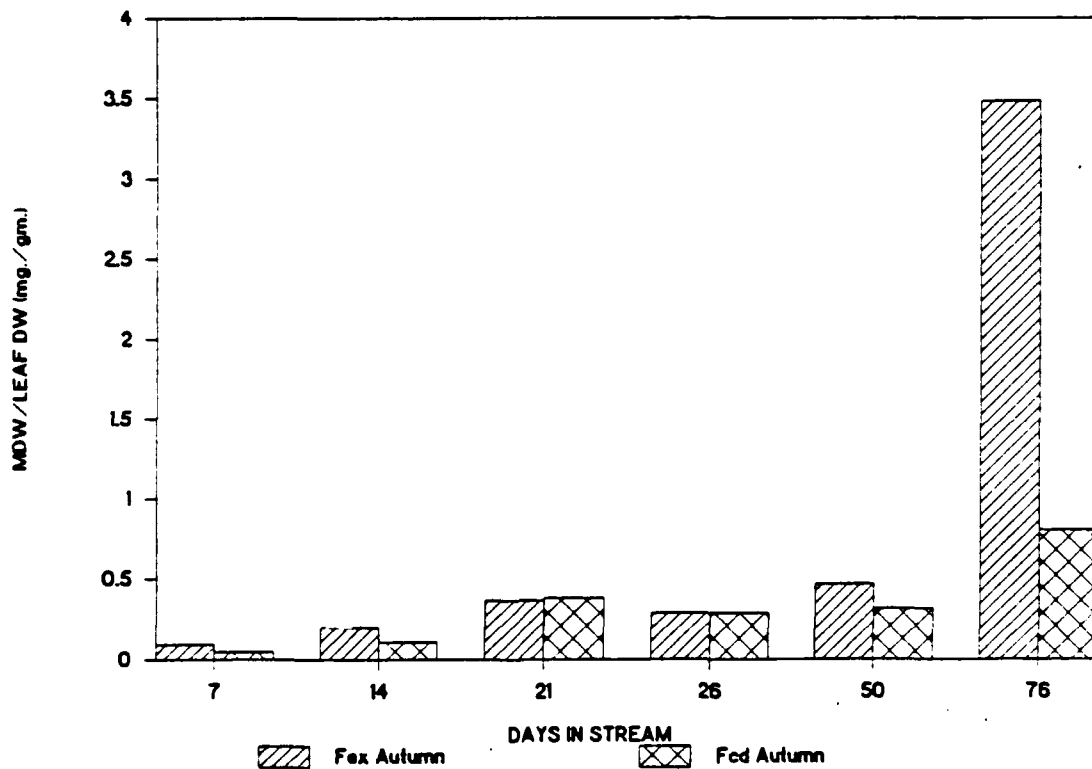


Figure 6.11A. Biomass of predators (adjusted to leaf mass) on fresh leaves for FEX and FCD sites, 1987.

Figure 6.11B. Biomass of predators (adjusted to leaf mass) on autumn leaves for FEX and FCD sites, 1987.

FIGURE 6.12A EPHEMERELLA INVARIA ON LEAVES, 1987

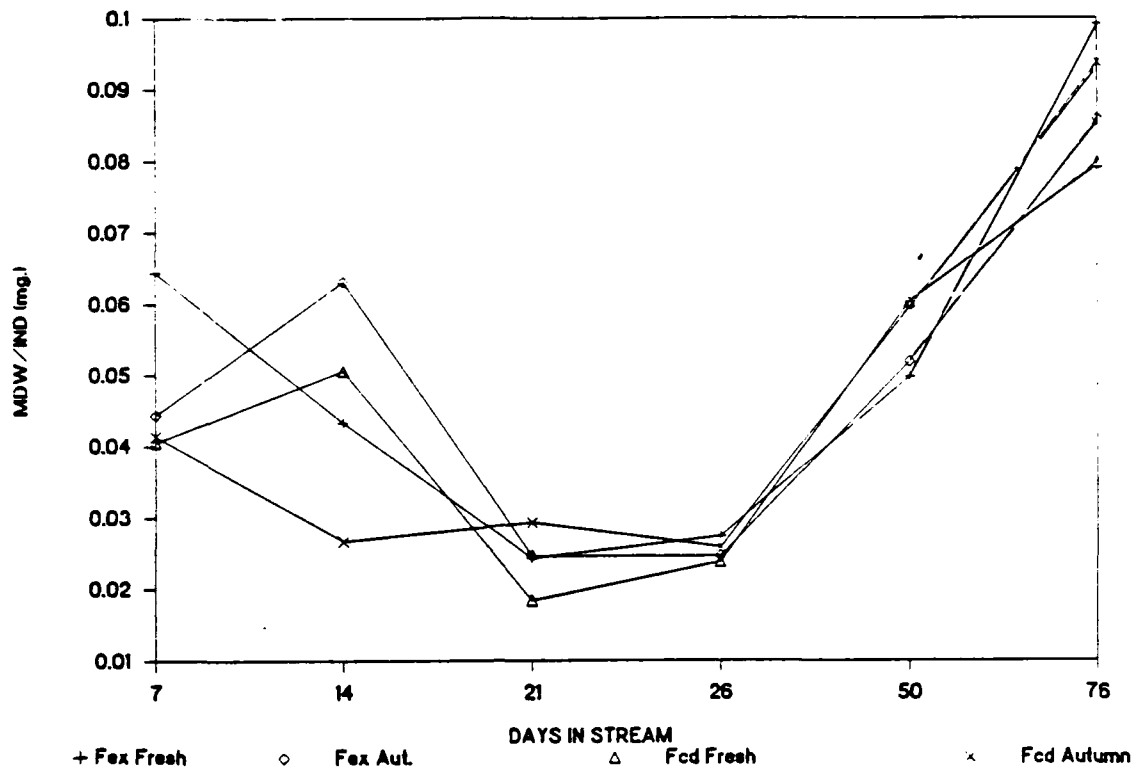


FIGURE 6.12B EPHEMERELLA SUBVARIA ON LEAVES, 1987

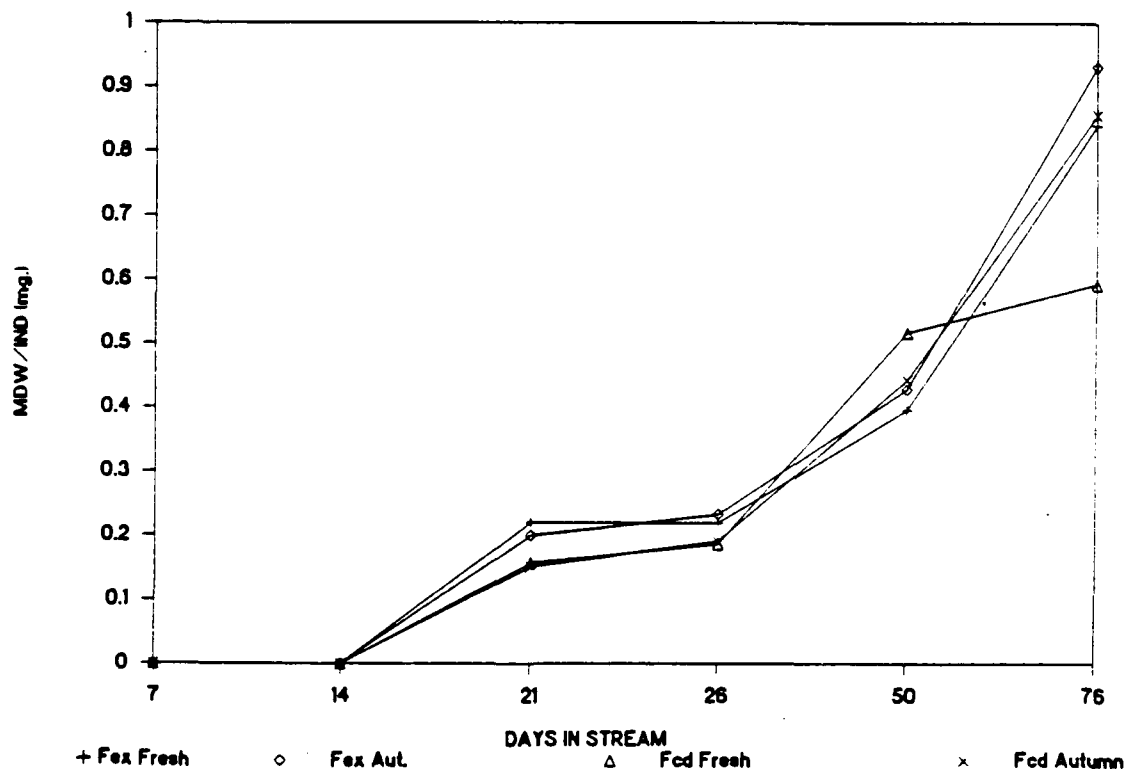


Figure 6.12A. Mean dry weight per individual values over time for Ephemerella invaria on fresh and autumn leaves at FEX and FCD sites, 1987.

Figure 6.12B. Mean dry weight per individual values over time for Ephemerella subvaria on fresh and autumn leaves at FEX and FCD sites, 1987.

specific reason for having larger animals colonizing the leaves in the early phases cannot be given. The second species in this genus, E. subvaria shows a much more consistent pattern (Figure 6.12 B). Young did not appear until September (Day 21). They increased in size on leaves at the two sites throughout the study. C.V. values throughout the period at the sites average 21%. MDW/IND values for these species as well as the next species to be described are also followed for substrate samples for Element 4 (this Report). Paraleptophlebia mollis showed very little growth until the last collection date (Figure 6.12C). This animal's major growth spurt is in May and June and so little in the way of size class changes is expected on leaves placed in the river during the fall. The last species, the predator Isoperla transmarina increased in size, especially after Day 26 (Fig. 6.12D). Few individuals of this species are found on the leafpacks. In the case of autumn leaves at FCD, there were only two individuals. The apparent loss in size is likely a function of few individuals rather than any real differences.

#### Comparisons, 1984 - 1987:

In 1984 through 1987, total insect biomass was higher on leaves at FEX than at FCD. Within FEX over that time, insects appeared to prefer fresh over autumn leaves as reflected by total insect biomass. In 1984, there were no collector-gatherer biomass differences between the two sites. In 1985, collector-gatherer biomass was higher at FEX than at FCD on Day 26. In 1986 that was also true on days 9 and 50. In 1987 collector-gatherer biomass was higher on leaves at FEX on days 7, 14, 21, 26, 50 and 76. As for total biomass, collector-gatherer biomass was higher on fresh than on autumn leaves. Fresh leaves may contain more nutritive value for micro-organisms on which the collector-gatherers feed. Given that there was more total biomass on leaves at FEX than on leaves at FCD, the differences between fresh and autumn leaves were more pronounced at the experimental site.

In 1982 and 1984 shredder biomass was higher on fresh than on autumn leaves over time. Shredder biomass in 1985-86 was significantly higher on fresh than on dried leaves on days 26, 105, and 135. In 1986 shredder biomass was significantly higher on fresh than on autumn leaves on days 3 and 27. In 1987, the variance for shredder biomass was high enough that mean differences between fresh and autumn leaves were insignificant. Often shredders biomass is higher on fresh leaves than autumn leaves (Figures 6.10A,B). Our data can be used to suggest that shredders prefer fresh leaves over autumn leaves.

The mean dry weight of the mayfly collectors, Ephemerella invaria and E. subvaria, consistently increased over time at FEX and FCD on all leaf treatments over the years, suggesting



FIGURE 6.12 PARALEPTOPHLEBIA MOLLIS ON LEAVES. 1987

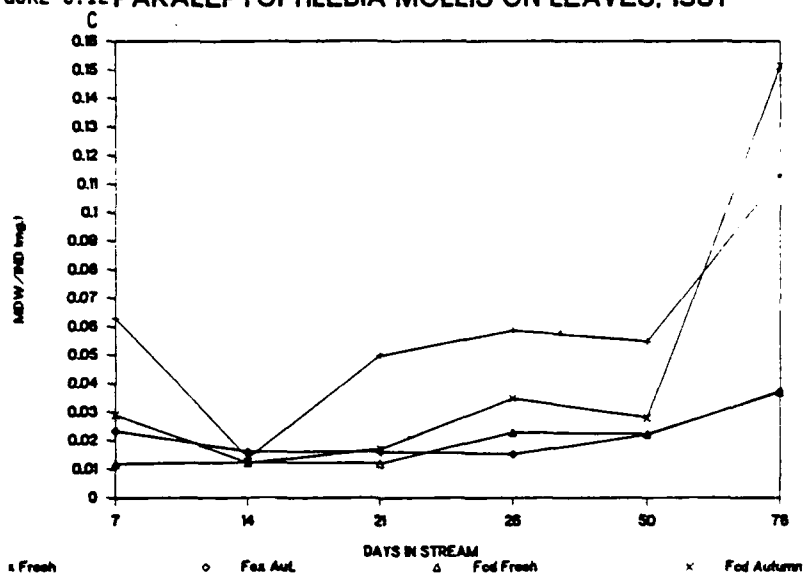


FIGURE 6.12D ISOPERLA TRANSMARINA ON LEAVES. 1987

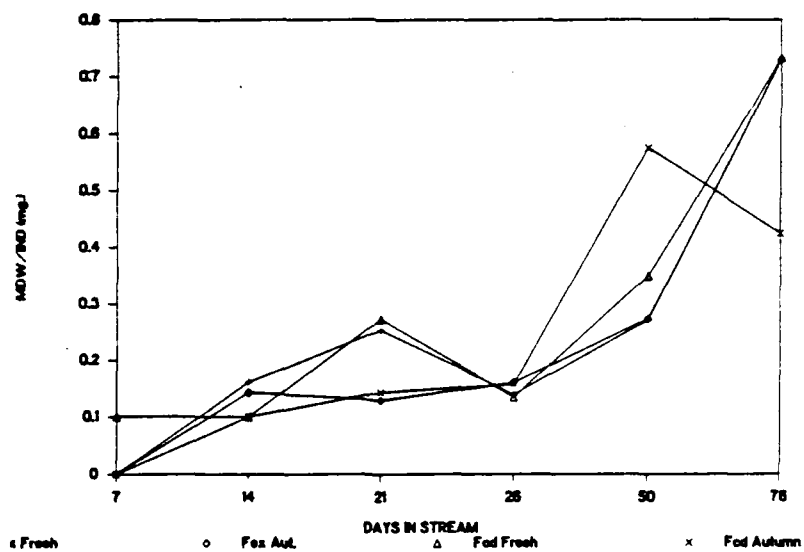


Figure 6.12 C. Mean dry weight per individual values over time for *Paraleptophlebia mollis* on fresh and autumn leaves at FEX and FCD sites.

Figure 6.12 D. Mean dry weight per individual values over time for *Isoperla transmarina* on fresh and autumn leaves at FEX and FCD sites.

that we are monitoring seasonal growth rates of these species, rather than site effects or leaf nutritive quality. The same is true for the predator, Isoperla transmarina. One collector-gatherer, Paraleptophlebia mollis, shows more variation among treatments and sites. Because this animal's major growth occurs in May - June and there is little growth in other months (See Element 4), these small nymphs show enough variation in size during leafpack studies that strong changes in size classes are not apparent. The species is monitored on leafpacks, however, for comparative purposes because it is also monitored in substrates (Element 4). The data are useful for comparing them with growth studies on another collector-gatherer mayfly by Webb (1987) in a study supported by the Aquatic Insects Task Group portion of this cooperative grant. MDW/IND values showed the most consistent and similar patterns across years as compared the other functional community parameters studied for this element.

#### Future Plans for this Element

Next year the fresh and autumn abscissed leaf studies will be initiated in mid-August as for 1987 and 1988. As in those years, we collected sufficient autumn leaves in the preceding fall of the study so that fresh and autumn leaves can be placed in the Ford River the same day in 1989. The collection days having the least variability for many parameters were days 21 and 26 to 28. We will continue, therefore, retrieving leaves after 7, 14, 21, 28, 50, and 76 days' immersion.

Coefficient of Variation (C.V.) values for  $-k$ ,  $H'$ ,  $J'$ ,  $S$  and biomass of selected species were low. Using a power test, seven replicates per treatment were sufficient over most of the collection dates to state that 95% of the time the true mean was less than + 40% of the estimated mean at an alpha level of 0.05. Seven replicates per treatment per site will continue to be taken in future years, as there these samples are relatively easy to process as compared with substrate samples. Some reviewers for prior annual reports suggested deletion of either fresh or autumn leaves, but we will continue to monitor both treatments as comparative data between site and treatment differences are important monitoring tools.

All parameters previously used will continue to be followed at the FEX and FCD sites. Changes in predator biomass along with selection of the most common predator species, Isoperla transmarina, will continue to be included in future work for this element.

Data on autumn leaves were used as part of a paper comparing leaf processing rates in tropical and mid-latitude streams (Stout, in press). Data on processing rates of fresh

Tag Alder leaves as well as White Oak (Quercus alba) in the Ford River and in a small stream in Costa Rica were used to initiate a large, cooperative project designed at comparing -k values for tropical, mid-latitude and boreal forest leaves. Processing coefficients for leaves in streams in their native habitats as well as in five other geographical areas were determined with the cooperation of five other researchers in Alaska, New York, North Carolina, Puerto Rico and Costa Rica. Results of these efforts will be presented at an upcoming biological meeting (A.I.B.S., August 1989). A paper will also be written, giving credit to the Navy contract, on these results.

### Summary

Leaf processing rates (-k) for fresh or autumn leaves at each of the sites were similar for all the years. Fresh leaves were processed fast; whereas, autumn leaves were processed at intermediate to slow rates. Diversity and evenness values were similar in 1982, 1984 and 1987 with an increase for the first month and thereafter a decrease in the index. In 1985 and 1986 there was a steady decrease after the first 9 days. Numbers of species (S) peaked by the end of a month's incubation of leaves and then diminished for all years. Percent dominance of chironomids on leaves was similar for all the studies; percent dominance increasing throughout the studies except for a slight depression after three week's incubation of the leaves. Mean number of individuals increased through the first month and then decreased by the end of the second month for all the studies. Total biomass of insects, adjusted to leaf mass consistently increased over time on fresh and autumn leaves and both sites. Highest biomass values were generally found at FEX. When there were treatment differences, the highest biomass values were found on fresh rather than autumn leaves. Although there are differences between FEX and FCD with respect to biomass of insects, the differences remained "stable" throughout the years. Any deviations from past patterns that occur at FEX after E.L.F. is fully operational will be suspect unless obvious non-anthropogenic environmental alterations have occurred. MDW/IND values for four species showed consistent increases over time. Because leaves were put in FEX and FCD earlier in 1987 than in previous years, the values were lower; however, the patterns of change across years remained the same for Ephemerella invaria, E. subvaria, Paraleptophlebia mollis and Isoperla transmarina. If changes in growth patterns for these species occur at FEX only after E.L.F. becomes fully operational, effects of E.L.F. on growth rates of those species should be detected.

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## Element 7 - Fish Community and Abundance

### 1. Species Composition

Eighteen species from six orders and eleven families were collected at FEX in 1988. This represents a net increase of one order, one family and two species from previous years. Twenty-one species from eleven families and six orders were collected at FCD in 1988 with an increase of three species from previous years. Overall, the species composition was similar at the two sites with the only changes seen in rare species.

### 2. Species Abundance

Numerically and by biomass, the fish community was dominated by five species. Numerically, common shiners and creek chubs made up over 55% of the catch at both sites. Burbot catch was the least variable, and common shiner, creek chub and brook trout catches were most variable. By biomass, white suckers and brook trout were the dominant species at FEX, making up 40.6% of the catch. At FCD, creek chubs and white suckers comprised 68.5% of the catch. Brook trout and white sucker catch in biomass was the most variable. Catch in biomass was more variable from year to year than catch in number. Overall, the fish species composition was similar from site to site and from year to year.

Species diversity decreased at both sites in 1987 from previous values. No significant differences were found between sites and the diversity values ranged between 1.54 to 2.2.

### 3. Catch Statistics

Catch rates (catch per day) were variable for all species and were seasonally dependent. At FEX, catch rates for common shiners and creek chubs increased dramatically in 1987 then decreased to average rates in 1988. White sucker catch rates at FEX also increased in 1987 then decreased in 1988. Brook trout and burbot continued negative trends in catch rates at FCD. Brook trout, burbot and white suckers all demonstrated similar catch rates at both sites and the differences can be attributed to increased habitat heterogeneity at FCD.

The mean length of most species showed no consistent year to year trends at either FCD or FEX, and brook trout, creek chubs and white suckers at FCD were significantly larger than their FEX counterparts.

#### 4. Fish Community Mobility

Most non-salmonid fish species with adequate sample sizes demonstrated site to site movement with most species showing a non-marking site recapture rate of 11.4%. Recapture percentages for 1988 were average when compared to previous years. Overall, site to site movements were lower in 1986, 1987 and 1988 than in previous years which may be attributed to significant discharge changes in these years.

#### 5. Individual Species Analyses

Age, growth and condition factor analysis using common shiners, creek chubs, northern pike and white suckers was initiated as a section of this element in 1986 with the premise that these factors are good indicators of fish stress. Growth analysis using scales indicated that common shiners and creek chubs show better than average growth when compared to values in the literature. White suckers and northern pike both displayed poor growth when compared to literature values. Fish condition was examined using relative condition factors. Standard weight formulas were derived for common shiners, creek chubs and white suckers from literature data. Common shiner condition was above the species average in each year. Creek chubs and white suckers demonstrated below species average condition ( $Wr=87-92$ ). Creek chub condition factors declined from 1983-1987 by 5% and then increased slightly in 1988. Common shiner condition showed a cyclic trend from 1983 - 1986 with a modulation of 7% per year then maintained a lower condition above the species mean for 1986 - 1988. White sucker condition improved by 8% since 1986.

#### 6. Fixed Gear Calibration

This study is designed to determine a functional relationship between fixed gear catch and actual fish densities. Net and weir catches can then be used to more accurately determine fish densities in the Ford River. DeLury estimates showed that fish densities and biomass declines from upstream sites to downstream sites. Also pre-movement (Spring) populations and biomass are higher than post-movement (Summer) estimates at all sites. Regression analysis of the relationships in this section will be reported after the 1989 season.

## Element 8 - Brook Trout Movement

### 1. Movement Patterns and Rates

Brook trout catches peaked in spring-early summer at all sites except FCU. The peak occurred in June in 1984, 1987 and 1988 and in July in 1985 with the movement in an upstream direction. Peak catches of 1984, 1985, 1987 and 1988 were not seen in 1986. Brook trout movement appeared to be initiated by mean daily water temperatures exceeding the optimal growth temperature (16 C). Movement rates are probably controlled by how quickly temperatures increase past optimal in spring. Low groundwater discharge and river flow volumes also may create thermal barriers to movement. Ground water recharge through spring snowmelt and precipitation are also important variables. Brook trout (>190 mm) move from FEX and FCD upstream to the TM site based on a total of 520 tagged and branded fish. In 1984 and 1985, TM was chosen over FCU on the basis of the mean temperature being closer to optimal growth temperature. Recapture rates were consistent from 1984 to 1985 with no movement found in 1986 and little in 1987 and 1988. Movement rates were found to range between 1.1 to 5.0 km/day. Ranges from FEX to TM were similar between 1984, 1985 and 1987 with no catches between these sites in 1986 and 1988. Brook trout movement rates were greater in 1985 than 1984 from FCD to TM with no movement detected in 1986 and 1988 and little in 1987. Angler tag return data verified the above movement rates indicating the fish move at a fairly constant measurable rate upstream.

### 2. Population Analysis

Michigan Department of Natural Resources conducted four electrofishing surveys at two sites on the Ford River. The brook trout density at FS1 in June 1985 was  $269 \pm 47.5$  per ha with biomass of 2.35 kg/ha. Most of these fish were YOY and yearling fish with very low densities of adult fish. Trout densities at FCD ranged from 60.7 fish/ha (biomass = 1.28 kg/ha) at pre-movement to 0 fish during the summer post-movement period. These densities are very low when compared to literature values and are probably indicative of the variable conditions of the Ford River. These data also indicate that a large percentage of the population moves out of the lower river (FCD site) in the Spring movement period.

ELF calibration studies determined the brook trout densities range from 0.0 fish/ha at FCD to 405.7 fish/ha at TM and that biomass ranges from 0.0 kg/ha at FCD to 14.7 kg/ha at TM. Overall values are below Michigan averages and show the recruitment is low at the sites sampled (except TM). Statistical analysis of the population characteristics



will be reported in the 1989 report.

### 3. Brook Trout Age, Growth and Condition

Age and growth analysis using scales indicated that the brook trout in the Ford River exhibit average or better growth when compared to literature values. Brook trout length at age 1 was approximately 90 mm, at age 2 was approximately 188 mm and at age 3 was approximately 285 mm. Statistical analysis of this data is in progress and will be reported in the next report. Brook trout condition was examined using relative weight condition factors (Wr). A standard weight formula was calculated from 45 literature populations for use in this analysis. Ford River brook trout demonstrated average to below average condition when compared to the species average (Wr 89 - 101). Condition factors declined from 1983 to 1986 and improved in 1987 and 1988. Statistical analysis of this data is in progress and will be reported in the next report.

## Element 7 - Fish Community Composition and Abundance

Changes from Synopsis - An analysis of the relationship between fixed gear catch and actual fish densities was added.

### Objectives

The overall objective of this element is to examine the effects of the Navy's ELF project on the fish community structure and movement in the Ford River. The specific objectives are to determine and monitor: 1) The fish community species composition, structure and relative abundance at both ELF sites; 2) The relative mobility of the fish community excluding brook trout in the Ford River; and 3) The age, growth, and condition of selected species in the Ford River. An additional objective was added in 1987 to determine a functional relationship between fixed gear catches and actual densities.

### Materials and Methods

#### A. Community Composition Studies

Two fyke net sites (FCD and FEX) and two weir sites (FCU and TM) were used in this study. The two fyke net sites were used in all parts of the study, and weir sites were operated only for the capture of fish marked at the lower sites for the fish community movement study. Sampling dates for 1983 through 1987 were reported in previous annual reports. Sampling for the 1988 season commenced on May 18 and continued when weather permitted until October 31. The number of sampling days for each year is reported in Figure 7.1.

At FCD and FEX, two 1/2 inch bar mesh fyke nets were fished (one facing upstream and one facing downstream). At FCU and TM, a weir constructed of 1/2 inch hardware cloth was used. The weir design was a variation of those used by Hall (1972). All gear was fished continuously for 4 sampling days per week when possible and checked every 24 hours.

All fish were enumerated, measured, weighed and marked by a fin clip distinctive for that site. The live fish were then returned to the water upstream or downstream from the station in the direction of travel.

#### B. Fixed Gear Calibration Study

Fixed gear calibration was performed using electrofishing gear, specifically a 250 volt DC unit, at sites at least one linear mile from net/weir sites to

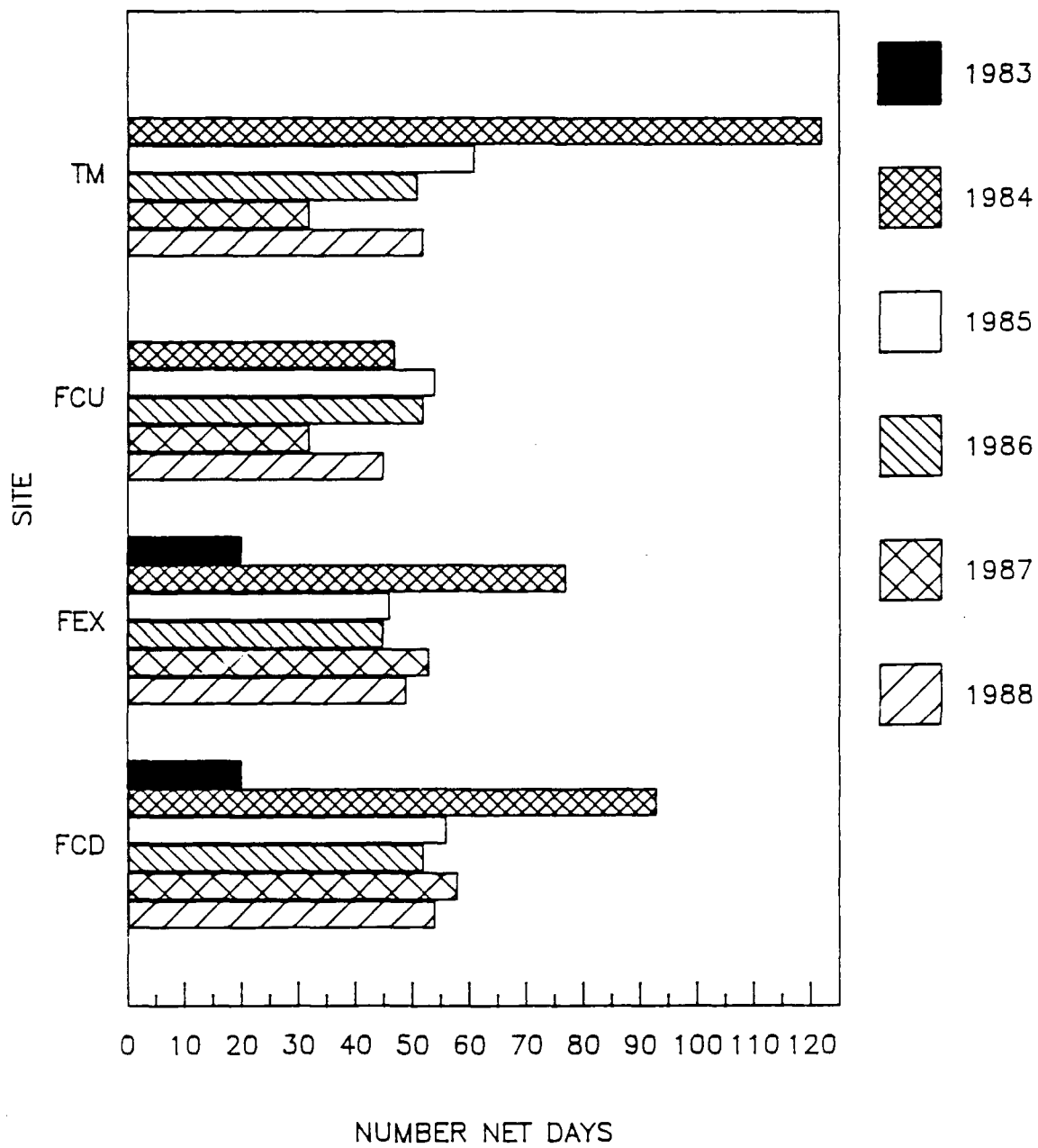


Figure 7.1. Number of net days at each site from 1983 through 1988.

minimize site contamination. Sites were selected with similar habitat characteristics as the actual research areas. Site locations, sampling dates and length are shown in Table 7.1. FCD and TM were sampled on three dates each and FEX and FCU were shocked twice. All sites were shocked during the pre-movement period (May) and during the post-movement period (late June-early July). At least three weeks were allowed between shocking dates to assure site recovery.

Population estimates were calculated using a three stage removal technique, the DeLury method. Three electrofishing passes were made at each site. All fish were enumerated and held in a holding cage constructed of 1/2 inch mesh hardware cloth until electrofishing was complete. A subsample of each species was additionally weighed and measured to obtain size distributions for comparison with net data.

Calculations were performed using the methodology outlined in Ricker (1975). Biomass estimates for selected species were made from the mean weight of the fish collected multiplied by the estimated number. Fixed gear catches will be related to electrofishing estimates using regression analysis. Brook trout density and site size structure data is reported in element 8.

## Results and Discussion

### A. Species composition

Eighteen species from six orders and eleven families were collected at FEX in 1988 (Table 7.2) using 1/2 inch bar mesh fyke nets. One more order, one family and two species were observed in 1988 compared to 1987. Two species, coho salmon (Oncorhynchus kisutch) and brown bullhead (Ictalurus nebulosis), were added to the species list in 1988. The number of families was three more than 1983 and 1987 and one more than 1984 through 1986. The changes in the overall FEX species composition can be attributed to changes in the catch of rare species.

The catch at FCD in 1988 consisted of twenty-one species from eleven families and six orders (Table 7.3). This represents an increase of three species from previous years. Golden shiner (Notemogonus crysoleucas), coho salmon (Oncorhynchus kisutch) and rainbow trout (Salmo gairdneri) were added to the species list at FCD. Again, as in the FEX samples, the only changes in the species composition occurred in the rare species which occur in low numbers.

As in the past, the species composition was higher at FCD than at FEX. All of the differences in the community composition between sites were in the uncommon species, thus overall the two sites continued to be similar in species composition.

Table 7.1. Location and description of electrofishing sites for fixed gear calibration objective in 1987 and 1988.

Site	Dates Sampled	Site Description	Length of Section
FEX	870701	1.6 linear miles downstream of FEX net site.	200 meters
	870826		200 meters
	880528		200 meters
	880714		200 meters
FCD	870727	1.2 river miles downstream of FCD net site. 300 meters upstream of Norway Lake Rd. Bridge.	200 meters
	870829		200 meters
	880524		200 meters
	880707		200 meters
	880826		200 meters
FCU	870818	300 meters downstream of weir site.	100 meters
	880527		100 meters
	880629		100 meters
TM	870817	1 river mile downstream of weir site. Directly upstream of Turner Truck Trail bridge.	200 meters
	880525		200 meters
	880630		100 meters
	880909		100 meters
FS1	870914	Directly downstream of the sediment trap.	200 meters



Scientific Name	Common Name	FEX				
		1983	1984	1985	1986	1987
Salmoniformes						
Esocidae						
<i>Esox lucius</i> (Linnaeus)	Northern pike	x	x	x	x	x
Salmonidae						
<i>Oncorhynchus kisutch</i> (Walbaum)	Coho salmon					x
<i>Salmo gairdneri</i> (Richardson)	Rainbow trout					x
<i>Salvelinus fontinalis</i> (Mitchill)	Brook trout	x	x	x	x	x
Umbridae						
<i>Umbra limi</i> (Kirtland)	Central mudminnow	x	x	x	x	x
Siluriformes						
Ictaluridae						
<i>Ictalurus nebulosus</i> (Lesueur)	Brown bullhead					x

Table 7.3. Fish species collected at FCD from May 1983 through October 1988 using 1/2" mesh fyke nets. Scientific names are from Robins et al. 1980.

Scientific Name	Common Name	FCD					
		1983	1984	1985	1986	1987	1988
<b>Clupeiformes</b>							
Clupeidae							
<i>Alosa pseudoharengus</i> (Wilson)	Alewife	x					
<b>Cypriniformes</b>							
Catostomidae							
<i>Catostomus commersoni</i> (Lacepede)	White sucker	x	x	x	x	x	x
<i>Hypentelium nigricans</i> (Lesueur)	Northern hog sucker			x			
Cyprinidae							
<i>Notemigonus crysoleucas</i> (Mitchill)	Golden shiner						x
<i>Notropis cornutus</i> (Mitchill)	Common shiner	x	x	x	x	x	x
<i>Pimephales promelas</i> (Rafinesque)	Fathead minnow				x		
<i>Phoxinus phoxinus</i> (Cope)	Northern redbelly dace	x					
<i>Rhinichthys atratulus</i> (Hermann)	Blacknose dace		x	x	x	x	x
<i>Rhinichthys cataractae</i> (Valenciennes)	Longnose dace	x	x	x	x	x	x
<i>Semotilus atromaculatus</i> (Mitchill)	Creek chub	x	x	x	x	x	x
<i>Semotilus margarita</i> (Cope)	Pearl dace	x	x	x	x	x	x
<b>Gadiformes</b>							
Gadidae							
<i>Lota lota</i> (Linnaeus)	Burbot	x	x	x	x	x	x
<b>Perciformes</b>							
Centrarchidae							
<i>Anblopiltes rupestris</i> (Rafinesque)	Rock bass	x	x	x	x	x	x
<i>Lepomis gibbosus</i> (Linnaeus)	Pumpkinseed		x	x			x
<i>Lepomis macrochirus</i> (Rafinesque)	Bluegill						x
<i>Micropterus dolomieu</i> (Lacepede)	Smallmouth bass		x			x	x
<i>Micropterus salmoides</i> (Lacepede)	Largemouth bass		x		x	x	x
Cottidae							
<i>Cottus bairdi</i> (Girard)	Mottled sculpin	x	x	x	x	x	x
Percidae							
<i>Percina maculata</i> (Girard)	Blackside darter	x	x	x	x		x



Scientific Name	Common Name	FCD				
		1983	1984	1985	1986	1987
Petromyzontiformes						
Petromyzontidae						
<i>Petromyzon marinus</i> (Linnaeus)	Sea lamprey	x	x	x	x	x
Salmoniformes						
Esocidae						
<i>Esox lucius</i> (Linnaeus)	Northern pike	x	x	x	x	x
Salmonidae						
<i>Oncorhynchus kisutch</i> (Walbaum)	Coho salmon					x
<i>Salmo gairdneri</i> (Richardson)	Rainbow trout					x
<i>Salvelinus fontinalis</i> (Mitchill)	Brook trout	x	x	x	x	x
Umbridae						
<i>Umbra limi</i> (Kirtland)	Central mudminnow		x	x	x	x
Siluriformes						
Ictaluridae						
<i>Ictalurus punctatus</i> (Lesueur)	Brown bullhead			x		x

## B. Species abundance

Numeric. The fish community at FEX was dominated by five species with the majority of the individuals caught from the cyprinid family (Table 7.4). Common shiners and creek chubs consisted of approximately 57.2% of the catch and this percentage has been consistent from year to year. The species structure was stable from year to year with all species having coefficients of variation on their combined percent catch of less than 45%. The catch component made up of common shiners was the most stable with a combined percent catch coefficient of variation of 6.6%. White suckers demonstrated the greatest fluctuation in number with a coefficient of variation of 42.4%. Overall, the community at FEX continued to be stable in relative numeric abundance with creek chubs and common shiners the dominant two species.

The relative numeric abundance of the catch at FCD was dominated by the same species as at FEX with the majority of the catch from the cyprinid family (Table 7.4). Common shiners and creek chubs were again the dominant species with over 75% of the catch and this percentage was consistent from year to year. This site also demonstrated a stable species abundance with all species except burbot having combined percentage catch coefficients of variation under 50%. Common shiners and creek chubs maintained the most stable catch components at FCD with a catch percentage coefficient of variation of 9.3% and 27.8% respectively. Burbot displayed the highest variability with a catch percentage coefficient of variation of 61.5%. The major difference between the two sites in 1988 was the higher percent catch of common shiners and creek chubs at FCD and lower percent catch of brook trout and burbot at FCD. These differences can probably be attributed to the differences in habitat between the two sites. Overall, the sites continued to be similar in species composition and demonstrated stable relative abundances from year to year. Thus, effects from ELF, if any, should be detectible through changes in these parameters.

Biomass. Catch percentage by biomass showed different trends in community structure than by number at both sites (Table 7.5). The FEX fish community was dominated in biomass by the same five species as was found by the numeric analysis although the dominant species changed. Brook trout and creek chubs dominated the catch biomass with 56.6% of the catch. Percent catch by biomass was comparable to percent catch by number at FEX with coefficients of variation of less than 50%. Burbot biomass was the most consistent (C.V.=20.8%) and white sucker catches were then most variable (C.V.=52.2%).

Table 7.4. Percent catch by number of the dominant fish species at FEX and FCD from May 1983 to October 1988 using 1/2" mesh fyke nets.

Species	1983	1984	1985	1986	1987	1988	Combined
	FEX						
Brook trout	12.3	10.2	16.0	10.6	14.7	4.9	11.5 ± 3.6
Burbot	20.1	24.1	12.9	13.4	11.5	10.9	15.5 ± 4.9
Common shiner	23.0	27.1	24.7	24.9	24.7	21.8	24.4 ± 1.6
Creek chub	22.7	16.6	33.3	29.7	22.4	35.4	26.7 ± 6.6
White sucker	8.8	8.6	5.6	14.8	20.8	16.6	12.5 ± 5.3
Other species	13.0	13.2	7.5	6.6	5.9	10.4	9.4 ± 2.9
	FCD						
Brook trout	13.8	11.3	10.6	6.7	4.9	2.4	8.3 ± 3.9
Burbot	17.0	6.0	8.3	9.5	4.8	1.7	7.8 ± 4.8
Common shiner	33.9	35.6	38.6	37.4	31.9	29.2	34.4 ± 3.2
Creek chub	21.1	25.4	26.2	27.9	31.9	46.9	29.9 ± 8.3
White sucker	5.5	13.1	7.6	9.3	21.3	15.5	12.1 ± 5.3
Other species	8.6	8.1	8.7	9.2	5.2	4.3	7.4 ± 1.9

Table 7.5. Percent catch by biomass of the dominant fish species at FEX and FCD from May 1983 to October 1988 using 1/2" mesh fyke nets.

Species	1983	1984	1985	1986	1987	1988	Combined
	FEX						
Brook trout	33.4	23.2	60.3	24.7	31.3	15.1	31.3 ± 14.2
Burbot	16.2	13.6	9.2	12.3	9.3	14.6	12.5 ± 2.6
Common shiner	10.1	3.5	9.7	13.8	11.5	9.9	9.8 ± 3.1
Creek chub	16.9	7.5	15.9	23.5	13.3	25.5	17.1 ± 6.0
White sucker	17.8	46.4	4.1	20.8	32.2	4.7	25.3 ± 13.2
Other species	5.6	5.8	0.8	4.9	2.4	0.2	4.0 ± 1.8
	FCD						
Brook trout	29.0	35.5	43.3	25.9	18.5	10.0	27.0 ± 10.8
Burbot	12.6	2.0	8.6	6.9	5.7	2.2	6.3 ± 3.7
Common shiner	17.2	4.0	18.5	18.6	20.8	14.7	15.6 ± 5.5
Creek chub	22.5	6.2	17.6	21.9	24.3	33.9	21.1 ± 8.5
White sucker	7.7	49.9	7.6	15.6	28.4	34.6	24.0 ± 15.3
Other species	11.0	2.4	4.4	10.1	2.3	4.6	5.8 ± 3.5

The catch biomass at FCD showed similar trends to FEX with the same five species dominating the catch (Table 7.5). Creek chubs and white suckers were the dominant species making up 68.5% of the biomass. The cyprinid biomass at FCD continued to be higher than at FEX. Coefficients of variation, however, were substantially higher at FCD than at FEX with values approaching 65%. Common shiner percent catch by biomass was the most stable (C.V.=35.3%) and white sucker percent catch by biomass were the most variable (C.V.=63.8%). Overall, the relative abundance by biomass showed similar trends at both sites with the major difference in the increase in percent cyprinid biomass at FCD.

Diversity. Shannon-Weiner diversity values showed a decrease at both sites in 1988 (Table 7.6). This trend was significant at both FEX and FCD (Kruskal-Wallis Test,  $p=0.05$ ). No significant differences were found between sites in index values in any year (Mann-Whitney U Test,  $p=0.05$ ). Overall, diversity values continued to be similar between sites and generally similar from year to year.

### C. Catch Statistics

Catch rates. Catch rates at both FEX and FCD showed a large amount of variance for all species as one would expect from catches having a negative binomial distribution (Table 7.7). White suckers, common shiners and creek chubs all have high spring-early summer catch rates because of spawning movements. Brook trout and burbot catch rates are also high in the early summer but this is attributed to water temperatures increasing above optimal for both species. White suckers also show an additional peak in juvenile fish in the late summer-early fall.

FEX catch rates for common shiners and creek chubs generally stayed the same from 1983-1986. In 1987 these species increased quite dramatically in catch per day. 1988 catch rates slid back to the average from previous years. White suckers showed a similar trend in 1988 (Figure 7.2) after increasing dramatically in 1987, 1988 rates returned to the average from previous years. Burbot catches showed no significant change during the 1983-1988 period.

Catch rates at FCD for common shiners, creek chubs and white suckers maintained the abnormally high patterns observed in 1987. Brook trout and burbot decreased slightly in average catch per day (Figure 7.2).

Catch rates were similar for brook trout, creek chubs and white suckers at both sites from 1983-1987. In 1988, however, catch rates of cyprinids were much higher at FCD than at FEX. Burbot catch rates were consistently higher at FEX than FCD. These differences can be attributed to

Table 7.6. Mean daily Shannon-Wiener diversity index values for FEX and FCD from 1983-1988.

Year	FEX	FCD
1983	$2.16 \pm 0.26$	$1.94 \pm 0.36$
1984	$2.20 \pm 0.56$	$2.03 \pm 0.33$
1985	$1.97 \pm 0.39$	$2.15 \pm 0.33$
1986	$1.62 \pm 0.48$	$1.87 \pm 0.31$
1987	$2.13 \pm 0.18$	$2.11 \pm 0.45$
1988	$1.62 \pm 0.34$	$1.54 \pm 0.27$

Table 7.7. Mean daily catch (standard deviation) for the dominant fish species at FEX and FCD from May 1983 to October 1988 using 1/2" mesh fyke nets.

Species	Year					
	1983	1984	1985	1986	1987	1988
	FEX					
Brook trout	4.3 (9.1)	2.2 (2.7)	2.5 (3.5)	2.5 (4.4)	7.8 (18.7)	1.1 (2.4)
Burbot	7.0 (6.6)	5.2 (4.0)	2.0 (3.3)	3.2 (4.7)	6.1 (6.5)	2.5 (3.5)
Common shiner	8.0 (10.1)	5.9 (6.6)	3.9 (5.8)	6.0 (8.9)	14.1 (25.7)	5.1 (10.7)
Creek chub	7.9 (7.8)	3.6 (5.5)	5.2 (7.1)	7.1 (9.5)	12.6 (17.1)	8.3 (17.2)
White sucker	3.1 (3.8)	1.9 (4.0)	0.9 (2.9)	3.6 (9.8)	11.0 (14.9)	3.9 (8.6)
	FCD					
Brook trout	3.8 (6.9)	3.4 (5.9)	2.7 (4.2)	1.7 (2.6)	3.1 (5.1)	1.5 (3.2)
Burbot	4.6 (3.7)	1.8 (2.1)	2.1 (2.3)	2.4 (3.0)	3.0 (4.1)	1.0 (1.7)
Common shiner	9.3 (10.0)	10.7 (13.3)	9.9 (11.2)	9.4 (13.0)	20.1 (31.1)	18.1 (30.4)
Creek chub	5.8 (10.1)	7.6 (18.9)	6.7 (8.0)	7.0 (7.2)	20.1 (23.9)	29.1 (69.3)
White sucker	1.5 (1.9)	3.5 (16.4)	2.0 (3.1)	2.3 (3.5)	12.6 (14.3)	9.6 (18.5)

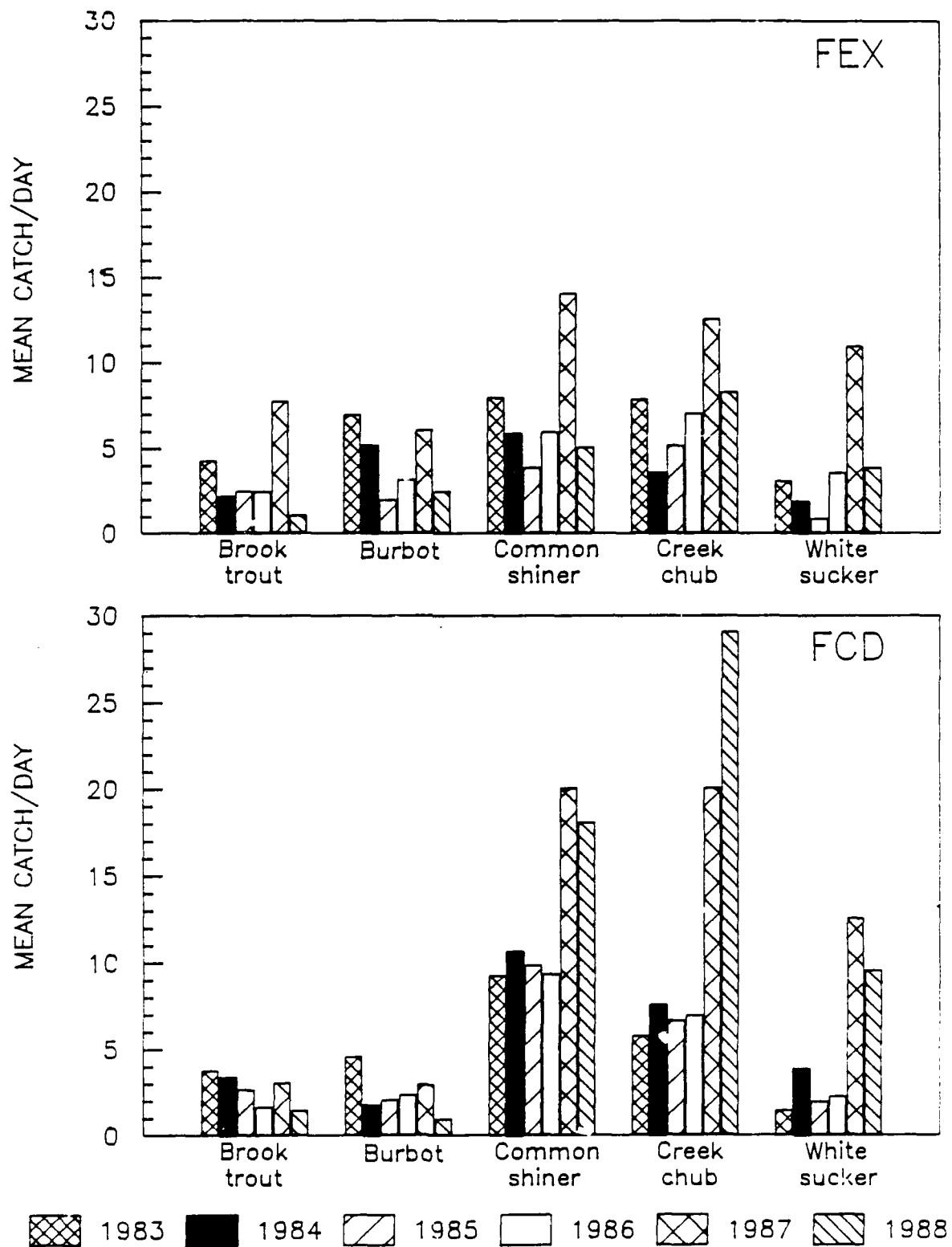


Figure 7.2. Mean daily catch for the dominant fish species at FEX and FCD for May 1983 to October 1988 using 1/2" mesh fyke nets.



habitat differences between the sites. Overall, catch rates continued to be similar and both sites showed a trend toward increasing catch rates for Cyprinid species. FEX and FCD showed decreased catch rates for brook trout and burbot.

Catch length. Mean length of most fish at FEX showed no trends from 1983-1988 (Figure 7.3). Brook trout and Creek chubs have shown a steady decline in mean size from 1984-88 but these changes have been slight. Overall, mean lengths of all species have remained fairly constant. This indicates that the size structure is consistent from year to year within the mobile fish community at FEX.

FCD has shown a similar pattern to FEX in that brook trout and creek chubs have decreased in length every year since 1984 (Figure 7.3). Brook trout and common shiners were generally significantly larger in mean length at FCD than FEX and burbot, creek chubs and white suckers showed no significant difference in mean length between sites (TTest  $P < 0.05$ ). Overall, the two sites continued to be similar in mean length and in trends in mean length. Therefore, ELF effects should be detectable through changes in growth.

#### D. Fish Community Mobility

Most non-salmonid species with adequate sample sizes demonstrated site to site movement as shown by the approximately 11.4% recapture rate at sites other than the marking site (Table 7.8a and b). In all, two to three times as many fish were marked in 1987 and 1988 than in past years due to the increased numbers of cyprinids in the catch. Overall recapture percentages were similar in 1988 to previous years except for white suckers which showed no site to site movement at all compared to a fairly high incidence of movement in the past. Site to site movement in 1988 for common shiners and creek chubs was similar to 1986 and 1987, and down approximately 50% and 140% respectively from 1984 and 1985. Burbot movement between sites decreased dramatically by 4.5 times from 1986, to rates below 1984 and 1985. In 1988 burbot movement increased to above the average from previous years to a level similar to 1986. Movement in 1984 and 1985 was similar for most species but showed more differences in 1986-1988 which may be attributable to the significantly lower discharge in these three years than in the previous two years (Freidman's Test,  $p < 0.05$ ). No fish were found to move more than 2 sites (26 km) in distance in 1986 through 1988. Overall, site to site movement in 1988 was similar to 1986 and 1987 and down from 1984 and 1985 which can be attributed to the lower spring discharges from 1986 through 1988.

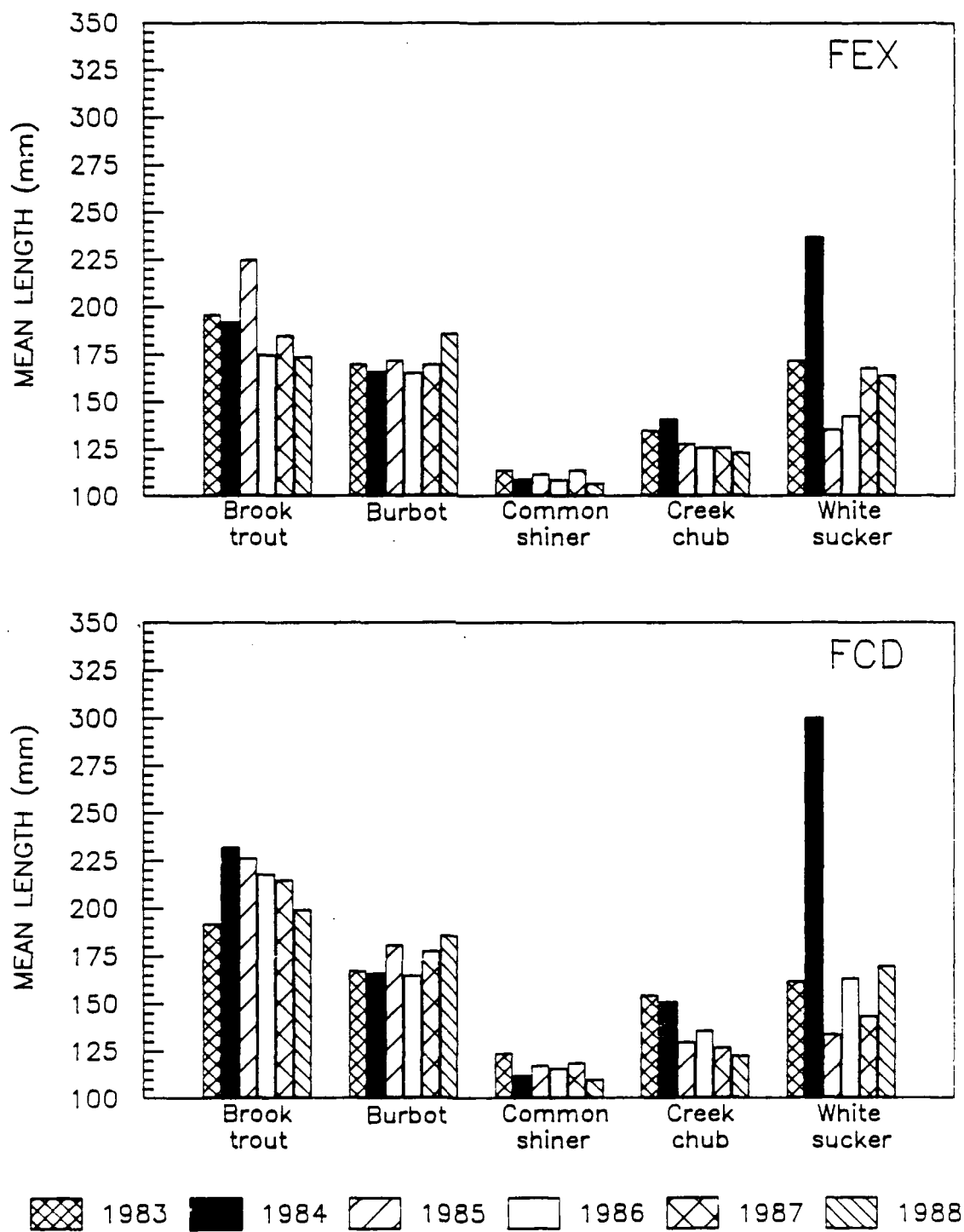


Figure 7.3. Mean length (mm) for the dominant fish species at FEX and FCD for May 1983 to October 1988.

Table 7.8a. Recapture data summary for all dominant species except brook trout from FEX and FCD for 1984 - 1986.

‡ Recapture by Location							
Species	Total Marked	Number Recaptured	‡ Recaptured	Marking Site	Upstream 1 Site	Down 1 Site	Up 2 Sites
1984							
Burbot	405	15	3.7	86.6	6.7	6.7	
Common shiner	1085	122	11.3	79.5	11.5	9.0	
Creek chub	700	72	10.3	81.9	12.5	5.6	
Longnose dace	110	22	20.0	72.8	13.6	13.6	
Northern pike	13	5	38.5	20.0	40.0	40.0	
White sucker	405	15	3.7	86.6	6.7		6.7
1985							
Burbot	170	22	12.9	86.3	4.5	9.2	
Common shiner	622	63	10.1	77.8	9.5	9.5	3.2
Creek chub	520	28	5.4	82.1	14.3		
Longnose dace	20	1	5.0	100.0			
Northern pike	5	0	0.0				
White sucker	125	2	1.6	100.0			
1986							
Burbot	218	15	6.9	80.0	13.3	6.7	
Common shiner	612	68	11.1	89.7	7.3	3.0	
Creek chub	535	31	5.6	96.8	3.2		
Longnose dace	44	2	4.5	50.0	50.0		
Northern pike	11	1	9.1	100.0			
Rock bass	56	7	12.5	71.4	14.3	14.3	
White sucker	259	12	4.6	75.0	16.7	8.3	

Table 7.8b. Recapture data summary for all dominant species except brook trout from FEX and FCD for 1987 and 1988.

Species	% Recapture by Location					
	Total Marked	Number Recaptured	% Recaptured	Marking Site	Upstream 1 site	Down 1 site 2 sites Up
1987						
Burbot	540	45	8.3	95.6	2.2	2.2
Common shiner	1693	172	10.2	88.4	10.5	1.2
Creek chub	1816	87	4.8	93.1	3.4	3.4
Longnose dace	192	3	1.6	100.0		
Rock bass	43	2	4.7	100.0		
Smallmouth bass	51	4	7.8	100.0		
White sucker	1530	42	2.7	78.6	9.5	9.5
1988						
Burbot	340	11	3.2	81.8	18.2	
Common shiner	1402	75	5.3	88.0	6.7	5.3
Creek chub	2649	96	3.6	90.6	4.2	5.2
Longnose dace	164	3	1.8	66.7	33.3	
Rock bass	30	2	6.7	100.0		
Smallmouth bass	19	1	5.3	100.0		
White sucker	1113	15	1.3	100.0		

## E. Individual Species Analyses

Introduction. Growth and condition of fish can be important indicators of a stressor on the well being of the fish. We have chosen four species; common shiner, creek chub, white sucker and brook trout as indicator species in this community to examine the potential effects of the ELF project on these two parameters. Brook trout data is reported on in element 8.

Age and Growth. Age and growth analyses on common shiners, creek chubs, northern pike and white suckers are reported in Table 7.9a-d). All analyses were done using scales and the body-scale relationship was calculated using the technique outlined in Smale and Taylor (1987). Backcalculation of length was done using the linear technique in Bagenal and Tesch (1978).

Common shiners exhibited better than average growth in the Ford River when compared to literature data in their third and fourth year (Carlander 1969). The first and second year growth is similar to that found in the literature. Lee's phenomenon is seen in all years which may reflect the selectivity of our sampling or differential mortality of different sizes of common shiners.

Creek chub growth in the Ford River was above the average growth rate in the literature for all ages (Carlander 1969). No Lee's phenomenon was observed in any year class.

Both white suckers and northern pike showed below average growth rates in the Ford River through all the age classes reported when compared to literature values (Carlander 1969). Reverse Lee's phenomenon was seen in white suckers with the age 4 fish having the best growth rates of the four years examined.

Age and growth analysis is complete on the 1984-1987 fish, and statistical comparisons to literature data and between years will be completed and reported in the final 1988 report. Additional investigations will include analysis of seasonal growth increment and yearly growth increment, and an examination of the effect of population size using CPUE and abiotic factors on growth. These analyses will allow us to separate the environmental and density-dependent factors from the ELF effects in the examination of growth.

Condition. Fish condition factors for common shiners, creek chubs and white suckers were performed using relative weight (Wr) condition factors as described in Wege and Anderson (1978). Standard weight formulas were calculated from 3 literature populations for common shiners, 5 literature populations for creek chubs and 13 literature

Table 7.9a. Mean backcalculated lengths for common shiners at all sites from 1983 through 1988.

		Backcalculated Length at Annulus			
		1	2	3	4
Age Class	N	$\bar{x} \pm \text{sd}$	$\bar{x} \pm \text{sd}$	$\bar{x} \pm \text{sd}$	$\bar{x} \pm \text{sd}$
1	7	42 $\pm$ 17.9			
2	41	39 $\pm$ 16.5	81 $\pm$ 14.4		
3	34	32 $\pm$ 11.6	73 $\pm$ 17.2	116 $\pm$ 21.8	
4	5	31 $\pm$ 8.9	71 $\pm$ 9.5	112 $\pm$ 14.8	160 $\pm$ 13.0
Overall Mean		36 $\pm$ 14.8	77 $\pm$ 15.9	115 $\pm$ 20.9	160 $\pm$ 13.0
		N=87	N=80	N=39	N=5

Table 7.9b. Mean backcalculated lengths for Creek chubs at all sites from 1983 through 1988.

		Backcalculated Length at Annulus			
		1	2	3	4
Age Class	N	$\bar{x} \pm \text{sd}$	$\bar{x} \pm \text{sd}$	$\bar{x} \pm \text{sd}$	$\bar{x} \pm \text{sd}$
1	42	$66 \pm 15.8$			
2	179	$63 \pm 15.7$	$105 \pm 24.0$		
3	91	$63 \pm 15.0$	$105 \pm 23.0$	$148 \pm 29.9$	
4	12	$69 \pm 22.8$	$113 \pm 24.6$	$158 \pm 27.5$	$199 \pm 30.7$
Overall Mean		$64 \pm 15.8$	$106 \pm 23.7$	$150 \pm 29.7$	$199 \pm 30.7$
		N=324	N=282	N=103	N=12

Table 7.9c. Mean backcalculated lengths for white suckers at all sites from 1983 through 1988.

Age Class	N	Backcalculated Length at Annulus					
		1	2	3	4	5	6
		x ± sd	x ± sd	x ± sd	x ± sd	x ± sd	x ± sd
1	33	73 ± 6.0					
2	35	73 ± 7.0	112 ± 13.6				
3	30	73 ± 6.4	114 ± 17.4	175 ± 29.9			
4	30	76 ± 10.3	126 ± 26.1	206 ± 54.0	285 ± 66.4		
5	22	77 ± 7.6	124 ± 24.4	202 ± 43.5	296 ± 53.1	369 ± 56.0	
6	13	75 ± 7.9	113 ± 14.3	191 ± 34.7	283 ± 45.6	360 ± 53.8	416 ± 55.5
Overall Mean		74 ± 7.6	118 ± 20.6	193 ± 43.8	287 ± 58.1	363 ± 55.6	411 ± 56.5
		N=164	N=131	N=96	N=66	N=36	N=14



Table 7.9d. Mean backcalculated lengths of northern pike  
at all sites from 1983 through 1988.

		Backcalculated Length at Annulus	
		1	2
Age Class	N	x ± sd	x ± sd
1	13	186 ± 32.4	
2	6	173 ± 20.9	249 ± 47.5
Overall Mean		182 ± 29.4 N=19	249 ± 47.5 N=6

populations for white suckers using the 50% percentile method outlined in Wege and Anderson (1978). Individual weights were then compared to the standard weights and given a  $W_r$  value based on the formula:  $W_r = \text{Fish weight} / W_s * 100$ . Mean values for 25 mm length groups for common shiners and creek chubs, and 50 mm white sucker were calculated for an unweighted analysis of the data with data pooled from FEX and FCD because of the high amount of mobility seen in the Ford River.

The  $W_s$  formulas for common shiners, creek chubs and white suckers are as follows:

Common shiners	$\log wt = -5.3907 + 3.1704 * \log tl$	( $r=.999$ )
Creek chubs	$\log wt = -4.8488 + 2.9295 * \log tl$	( $r=.998$ )
White suckers	$\log wt = -4.9820 + 3.0073 * \log tl$	( $r=.98$ )

where,

$wt$  = weight  
 $tl$  = total length

Condition factors for creek chubs and white suckers were below the species mean by from 4-20% possibly reflecting the highly variable abiotic conditions in the Ford River (Figure 7.4). Common shiner  $W_r$  values were above the species mean in all years which may be interpreted as showing that the Ford River has the proper habitat to meet the requirements of this species. Creek chubs declined in condition from above the species mean to approximately 9% below the species mean in 1987 and 1988. White sucker condition increased by 4% in 1987 and 1988 ending a 4 year decline in relative weight values. Common shiners, which had shown a wave trend in  $W_r$  from 1984-1986, maintained a level similar to 86 in 1987 and 1988. Additional analysis examining the effect of population size using CPUE and abiotic factors on  $W_r$  are in progress; and a statistical analysis of year to year variation are in progress.

#### F. Fixed Gear Calibration Study

This study is designed to determine a functional relationship between fixed gear catches and concurrent population densities. This relationship will allow us to calculate actual densities from all net catches and greatly increase the available analyses to examine the effects of the ELF project.

Preliminary population and biomass estimates for all sites are reported in Tables 7.10a-d. Electroshocking efficiencies for 1988 ranged from 0.410 for longnose dace to 0.721 for white suckers (Table 7.11). Overall, fish densities and biomass decline from upstream (TM and FCU) to

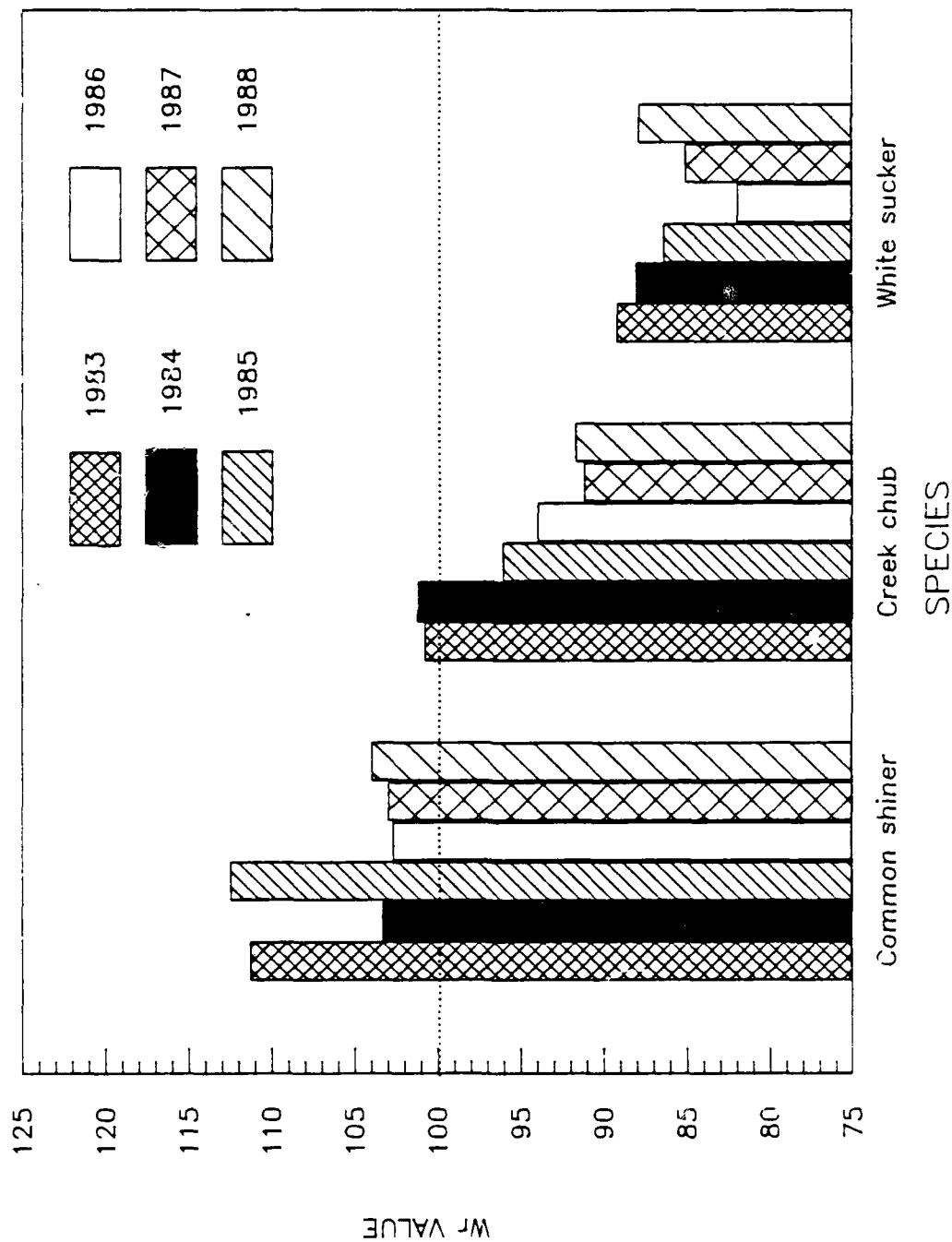


Figure 7.4. Yearly unweighted relative weight values for common shiners, creek chubs and white suckers in the Ford River. Dotted line at 100 indicates a condition equal to the average calculated from several literature populations.

Table 7.10a. Delury population estimates ((number/hectare), biomass (kilograms/hectare)) for all species excluding brook trout at FEX from 1987 and 1988.

DATE	SPECIES	LOWER 95% CI	ESTIMATE	UPPER 95% CI	BIOMASS
870701	Burbot	0.0	91.7	242.1	3.66
	Central mudminnow	0.0	8.3	28.7	
	Common shiner		4.2		0.02
	Creek chub	0.0	12.5	35.4	0.05
	Longnose dace	11.8	50.0	88.2	0.13
	Mottled sculpin	0.0	83.3	170.8	0.51
870826	Blacknose dace	90.2	95.8	101.3	
	Blackside darter	0.0	83.3	304.9	
	Burbot	51.3	79.2	107.2	2.80
	Central mudminnow		8.3		
	Common shiner	109.5	112.5	115.4	
	Creek chub	462.9	487.5	512.0	
	Fantail darter	28.3	36.0	46.6	
	Johnny darter		4.2		
	Longnose dace	138.7	179.2	219.6	
	Mottled sculpin	81.7	145.8	210.0	
	Rock bass		4.2		0.22
	Smallmouth bass	7.1	20.8	34.6	0.09
	White sucker	97.9	129.2	160.0	11.87
880523	Blacknose dace	50.5	55.1	80.7	0.16
	Blackside darter	45.9	45.9	57.3	0.18
	Burbot	73.4	82.6	115.6	2.90
	Common shiner	41.3	55.1	120.6	0.35
	Creek chub	133.0	151.4	192.7	1.37
	Fantail darter	68.8	100.9	210.1	
	Johnny darter	73.4	73.4	82.1	0.15
	Longnose dace	68.8	100.9	210.1	0.39
	White sucker	18.4	18.4	21.6	0.78
880714	Burbot	59.6	59.6	70.6	2.09
	Common shiner	490.8	536.7	590.4	3.39
	Creek chub	603.7	743.1	883.0	6.74
	Johnny darter	55.1	55.1	60.6	0.11
	Longnose dace	45.9	45.9	54.6	0.18
	White sucker	160.6	160.6	167.4	6.88

Table 7.10b. Delury population estimates ((number/hectare), biomass (kilograms/hectare)) for all species excluding brook trout at FCD from 1987 and 1988.

DATE	SPECIES	LOWER 95% CI	ESTIMATE	UPPER 95% CI	BIOMASS
870727	Burbot	67.5	70.8	74.2	2.44
	Central mudminnow	20.3	29.2	38.0	
	Common shiner	49.7	54.2	58.7	
	Creek chub	152.6	158.3	164.1	3.80
	Longnose dace	100.3	100.3	115.4	
	Mottled sculpin	67.9	75.0	82.1	
	Pearl dace		4.2		
870829	White sucker	59.9	62.5	65.1	1.93
	Blacknose dace		4.2		
	Blackside darter	140.4	162.5	184.6	
	Burbot	44.2	54.2	64.1	1.36
	Central mudminnow	23.2	25.0	26.5	
	Common shiner	0.0	8.3	63.3	
	Creek chub	58.8	112.5	166.3	
880524	Longnose dace	102.9	166.7	226.3	
	Mottled sculpin	145.5	166.7	187.9	
	White sucker	77.5	87.5	97.6	
	Blackside darter	43.0	49.6	56.2	0.20
	Burbot	35.7	37.2	48.7	1.31
	Common shiner	64.4	74.3	84.2	0.47
	Creek chub	251.9	218.8	304.3	2.28
880707	Fantail darter	7.0	20.6	34.3	
	Johnny darter	49.1	53.7	58.2	0.11
	Longnose dace	156.9	189.9	251.9	0.74
	Mottled sculpin	78.5	90.8	127.6	0.48
	White sucker	0.0	12.4	35.1	0.53
	Burbot	28.1	33.0	38.0	1.16
	Common shiner	177.5	189.9	216.8	1.20
880826	Creek chub	268.4	346.8	455.0	3.15
	Longnose dace	23.1	28.9	34.7	0.11
	White sucker	180.4	185.8	191.2	7.95
	Blackside darter		20.6		0.08
880826	Burbot	35.9	45.4	54.9	2.46
	Common shiner		8.3		0.05
	Creek chub	66.1	70.2	90.0	0.60
	Johnny darter		28.9		0.06
	Longnose dace		24.8		0.10
	Smallmouth bass		12.4		
	White sucker		20.6		0.88

Table 7.10c. Delury population estimates ((number/hectare), biomass (kilograms/hectare)) for all species excluding brook trout at FCU and FS1 from 1987 and 1988.

DATE	SPECIES	LOWER 95% CI	ESTIMATE	UPPER 95% CI	BIOMASS
FCU					
870818	Blacknose dace	606.8	844.4	1082.1	
	Blackside darter	123.2	144.4	165.7	
	Burbot	94.7	100.0	102.5	2.63
	Creek chub	135.9	155.6	175.2	
	Longnose dace	1444.4	1622.2	1800.0	
	Mottled sculpin	537.6	577.8	617.8	
	White sucker		11.1		0.10
880527	Blacknose dace	1104.5	1253.7	1453.7	3.64
	Burbot	0.0	44.8	126.9	1.57
	Creek chub	298.5	313.4	370.2	2.84
	Longnose dace	1283.6	1328.4	1409.0	5.15
	Mottled sculpin	313.4	328.4	394.0	1.75
880629	Blacknose dace	1895.5	2014.9	2153.7	5.84
	Blackside darter	223.9	268.7	417.9	1.06
	Burbot	41.8	74.6	107.5	2.62
	Creek chub	434.3	462.7	491.0	4.20
	Johnny darter	194.0	209.0	288.1	0.42
	Longnose dace	656.7	1119.4	2050.8	4.34
FS1					
870914	Blacknose dace	291.5	450.0	608.5	
	Blackside darter	0.0	575.0	1241.5	
	Burbot	15.8	41.7	67.1	1.91
	Creek chub	146.0	290.0	433.8	
	Longnose dace	0.0	1975.0	8475.0	
	White sucker	40.4	45.8	51.2	3.44

Table 7.10d. Delury population estimates ((number/hectare), biomass (kilograms/hectare)) for all species excluding brook trout at TM from 1987 and 1988.

DATE	SPECIES	LOWER 95% CI	ESTIMATE	UPPER 95% CI	BIOMASS
870817	Blacknose dace	69.3	78.6	87.7	
	Blackside darter	75.9	92.9	110.0	
	Burbot	160.0	171.4	182.5	5.88
	Creek chub	0.0	164.3	609.3	
	Longnose dace	2850.0	3578.6	3969.3	
	Mottled sculpin	213.9	357.1	500.0	
	White sucker		7.1		0.46
880525	Blacknose dace	39.2	57.0	74.7	0.17
	Burbot	38.0	113.9	189.8	4.05
	Creek chub	14.6	25.3	36.1	0.23
	Longnose dace	1487.3	3708.9	6360.8	14.57
	Mottled sculpin	208.9	544.3	1686.7	2.94
880630	Blacknose dace	544.3	569.6	634.2	1.67
	Blackside darter	106.3	113.9	121.5	0.45
	Burbot	63.3	76.0	192.4	2.70
	Longnose dace	4548.1	5582.3	6616.5	21.94
	Mottled sculpin	253.2	278.5	362.0	1.50
880909	Blacknose dace	316.5	367.1	493.7	1.08
	Blackside darter	169.6	189.9	210.1	0.76
	Burbot	177.2	215.2	351.9	1.07
	Creek chub	131.7	151.9	172.2	1.39
	Longnose dace	2329.1	5139.2	8535.4	20.20
	Mottled sculpin	139.2	177.2	331.7	0.94
	White sucker		38.5		1.65

Table 7.11. Mean electrofishing efficiencies (s.d.) for all sites in 1987 and 1988.

Species	1987		1988	
	N	Mean Efficiency (s.d.)	N	Mean Efficiency (s.d.)
Blacknose dace	5	0.655 (0.266)	6	0.547 (0.066)
Blackside darter	5	0.464 (0.248)	5	0.658 (0.145)
Brook trout	7	0.771 (0.234)	9	0.571 (0.158)
Burbot	7	0.619 (0.225)	9	0.501 (0.182)
Central mudminnow	4	0.713 (0.110)		
Common shiner	4	0.777 (0.209)	4	0.535 (0.135)
Creek chub	7	0.515 (0.215)	8	0.543 (0.122)
Fantail darter	1	0.643	2	0.431 (0.176)
Johnny darter	1	1.000	5	0.648 (0.125)
Longnose dace	7	0.441 (0.200)	3	0.410 (0.214)
Mottled sculpin	7	0.486 (0.177)	6	0.438 (0.159)
Pearl dace	1	1.000		
Rock bass	1	1.000		
Smallmouth bass	1	0.556		
White sucker	6	0.805 (0.183)	4	0.721 (0.147)



Downstream (FEX and FCD). This can be attributed to the increased complexity of habitats found at the upstream sites. Regression analysis of fixed gear and electrofishing catches will be reported on in a later report when more data will be available.

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## Element 8 - Brook Trout Movement

Changes from synopsis - none.

### Objectives

The overall objective of this element is to examine the effects of the Navy's ELF project on brook trout (Salvelinus fontinalis). Brook trout are well known to be sensitive to thermal changes and appear to move to avoid suboptimal conditions in the Ford River as shown previously. Any migration limitations or exclusion induced by ELF could cause severe physiological problems since trout are less efficient bioenergetically in water above 16 C. The specific objectives of this element are to determine: 1) The seasonal pattern and magnitude of brook trout movement through the ELF corridor; 2) Brook trout movement rates through the ELF corridor; 3) The mechanism for these movements; and 4) The population characteristics of brook trout in the Ford River.

### Materials and Methods

The sites and gear used in this element were previously described in element 7. All brook trout were removed on a daily basis from the traps and anesthetized with MS-222 to reduce handling stress at a 500 mg/l dosage as recommended by Meister and Ritzi (1958), and Schoettger and Julin (1967) for hard water applications. All brook trout were then enumerated, measured and weighed. For 1983-1987 a subsample of fish was tagged using different tagging techniques. Due to either a high incidence of tag loss or high tagging mortality in past years, brook trout were not tagged in 1988. All 1988 fish were given a traditional site specific fin clip. All fish were released upstream or downstream from the site in the direction of travel after a recovery period.

Data analysis examining the role of physical and chemical factors on brook trout movement at FEX and FCD was done using ambient monitoring data. Physical and chemical data at FCU and TM was collected by the fisheries staff from 1984-87. Flow was calculated from a calibrated staff gauge at both FCU and TM on a daily basis. Temperature data was collected continuously using a calibrated max-min thermometer at TM and FCU. Chemical data (DO, pH, and alkalinity) was collected on a bi-weekly basis at TM and FCU using standard methods and is summarized in Table 8.1.

Population estimates, in conjunction with the gear calibration, were obtained using electrofishing gear as described in element 7. Site locations are also listed in Table 7.1.

Table 8.1. Water quality data from 1983-1988 at Two Mile Creek and FCU.

Parameter		Site	
		TM	FCU
DO	(mg/L)	9.3	9.9
pH		7.5	7.6
Alkalinity	(CaCO <sub>3</sub> /L)	143.6	168.8
Hardness	(CaCO <sub>3</sub> /L)	---	189.2
Turbidity	(NTU)	---	1.4
Conductivity	(umhos)	---	271.2

## Results and Discussion

### A. Marking Statistics

Numbers of fish tagged declined from a high of 314 in 1984 to 82 in 1986 because of a lack of fish caught in our gear (Table 8.2). The sample size of tagged fish increased in 1987 to 170 fish. As mentioned earlier, trout were only fin clipped in 1988. The between site recapture rate was consistent in 1984 and 1985, fell to 0% in 1986 and remained low in 1987 and 1988. Tagging mortality averaged 6.2% from 1984 to 1987 which is probably an underestimate because we are only examining fish which float back into nets and fish that we find on regular searches of the study area. No handling mortality was observed in 1988. The percentage of angler returns also declined from 12.1% in 1984 to 3% in 1985 and 0% in 1986-1988. This probably reflects a decrease in the total number of fish retaining tags, adverse weather patterns and a decrease in the amount of angler effect.

### B. Brook Trout Catch Patterns

Brook trout catches peaked in the spring-early summer at all sites except FCU. Since catch patterns were similar at all sites, data will be presented from FCD as example data in this report (Figures 8.1 a-c). In 1984, the mean daily catch was at its maximum in the first week of June at 15.8 brook trout collected per day with the high catch patterns continuing for three weeks. A similar pattern was seen in 1985 although delayed by one month until the first week of July when 11.7 brook trout per day were collected and this continued for only an one week period. Catch rates decrease rapidly after this week to between 0-1 fish per day. This pattern did not continue in 1986. Catch rates in 1986 were higher in late May and early June than later in the year but the peak catch rates of 1984 and 1985 were not repeated. Results in 1987 were similar in distribution to the 1984 catch rates although the peak occurred two weeks later. In 1988 catch rates started to increase the last two weeks of May and peaked at 10.5 fish/day during the first week of June as in 1984. Movement in the upstream direction was significantly higher than the downstream movement in all years at all sites (Mann-Whitney U Test,  $p < 0.05$ ). In summary, the brook trout showed a consistent upstream movement pattern in the spring-early summer of all sampling years although the intensity and timing varied from year to year. This directed movement will be analyzed closely as ELF becomes 100 % operational in 1989. If trout have difficulty orienting through the corridor, we will be able to observe this effect through decreased upstream movement, especially at the FEX site.

Table 8.2. Brook trout marking and recapture summary for FEX and FCD for 1984 - 1988.

Year	Tag Summary	Site	
		FEX	FCD
1984	Number Tagged	71	243
	Number Fin Clipped	48	37
	Percent Tag Recapture	18.2%	
	Estimated Tagging Mortality	5.7%	
	Percent Angler Recapture	12.1%	
1985	Number Tagged	45	81
	Number Fin Clipped	38	53
	Percent Tag Recapture	12.7%	
	Estimated Tagging Mortality	8.7%	
	Percent Angler Recapture	3.0%	
1986	Number Tagged	15	40
	Number Branded	19	8
	Number Clipped	58	32
	Percent Tag Recapture	0.0%	
	Estimated Tagging Mortality	3.4%	
1987	Percent Angler Recapture	3.0%	
	Number Tagged	97	73
	Number Clipped	127	41
	Percent Tag Recapture	0.1%	
	Estimated Handling Mortality	7.1%	
1988*	Percent Angler Recapture	0.6%	
	Number Clipped	57	85
1988*	Estimated Handling Mortality	0.0%	

\* No tagging done in 1988 due to the lack of an effective method.

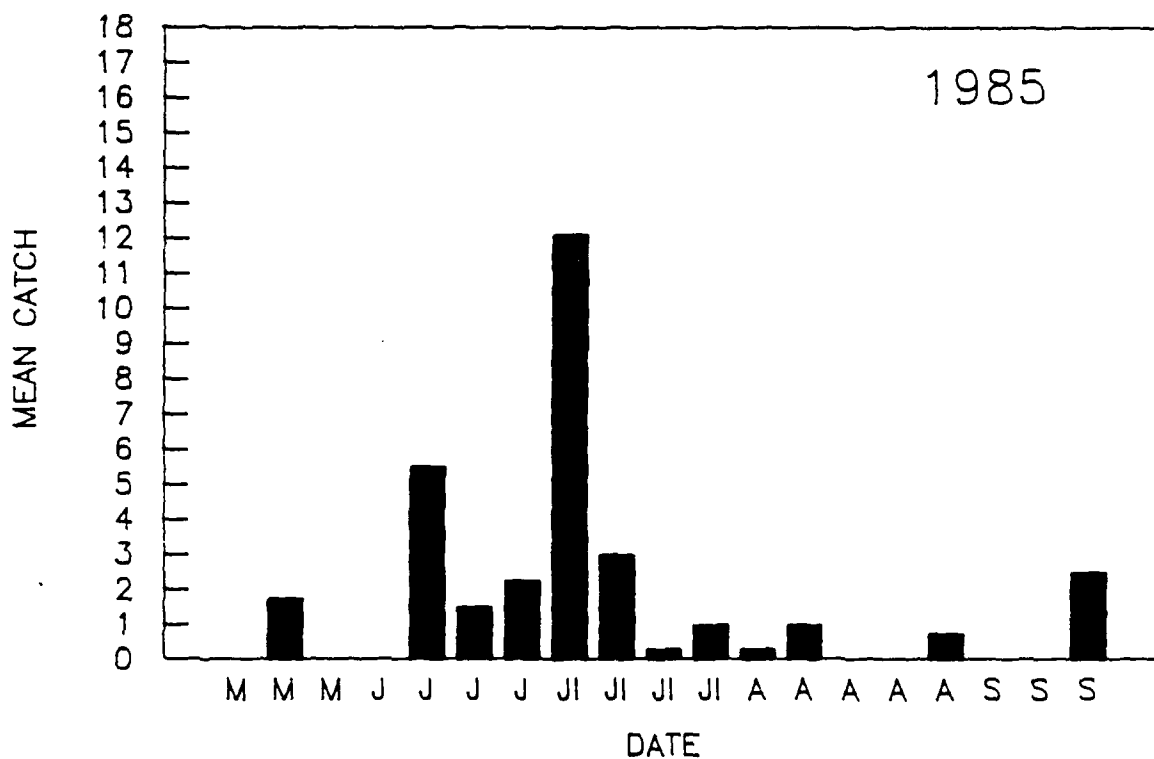
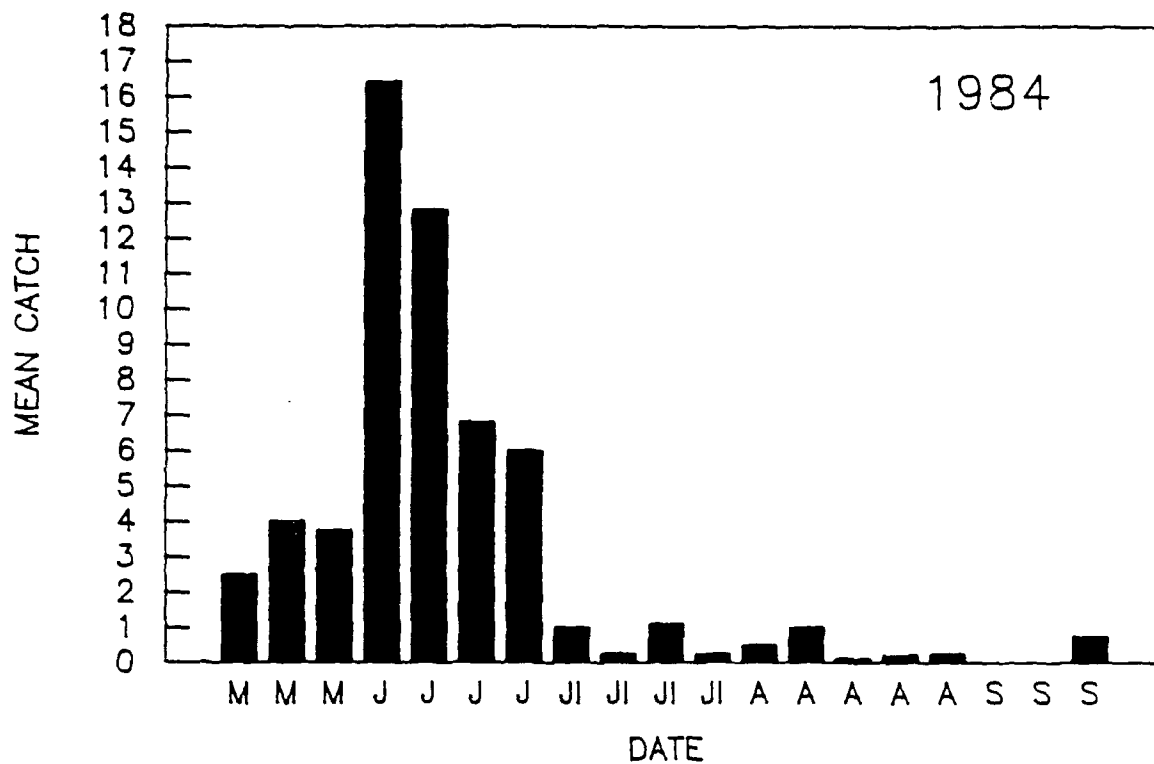


Figure 8.1a. Mean daily catch of brook trout plotted on a weekly basis at FCD from 1984 and 1985.

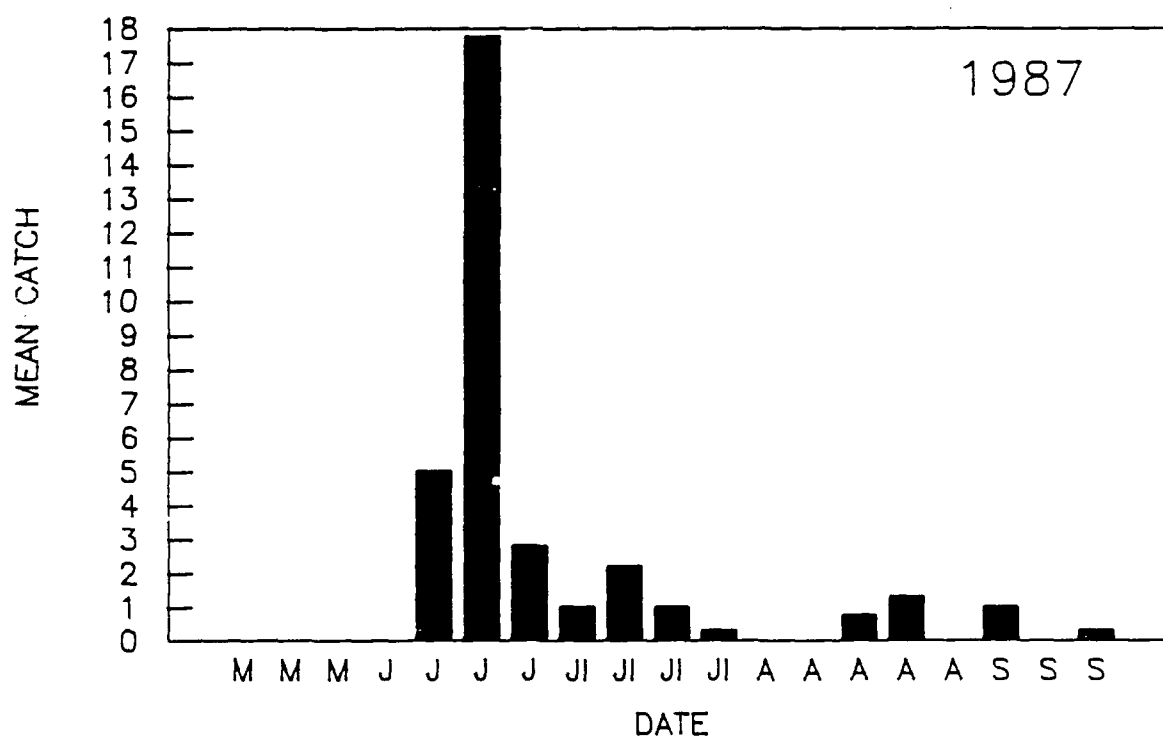
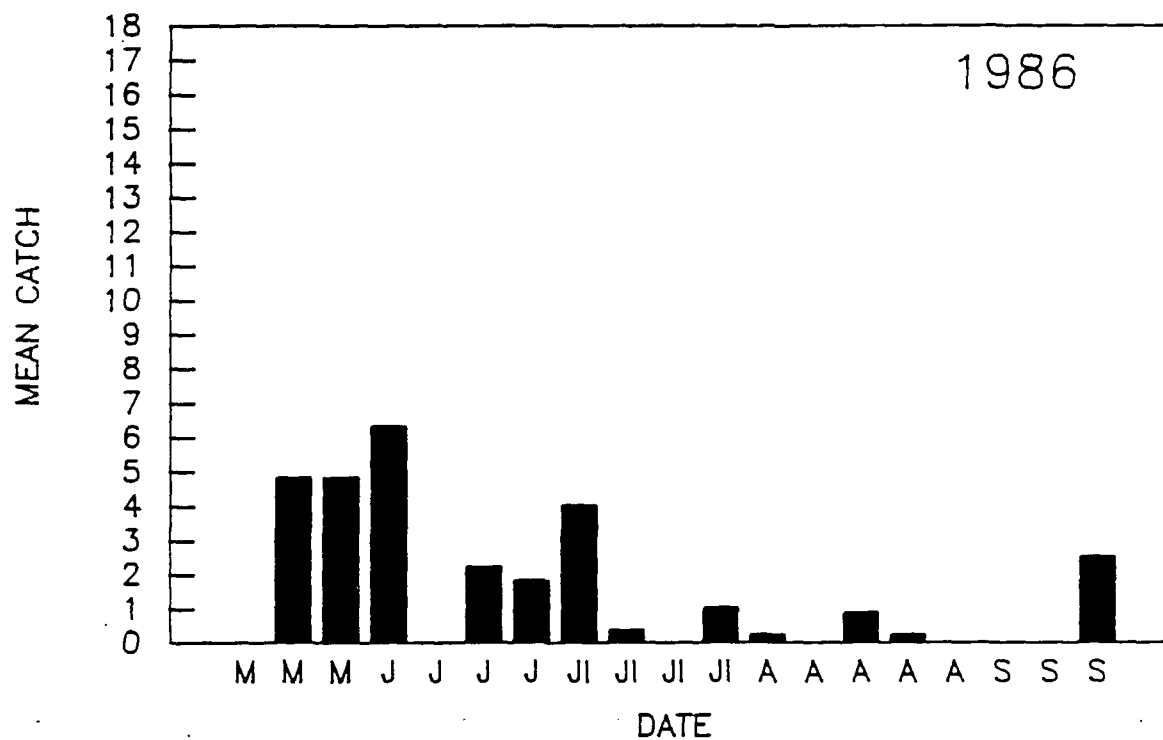


Figure 8.1b. Mean daily catch of brook trout plotted on a weekly basis at FCD from 1986 and 1987.



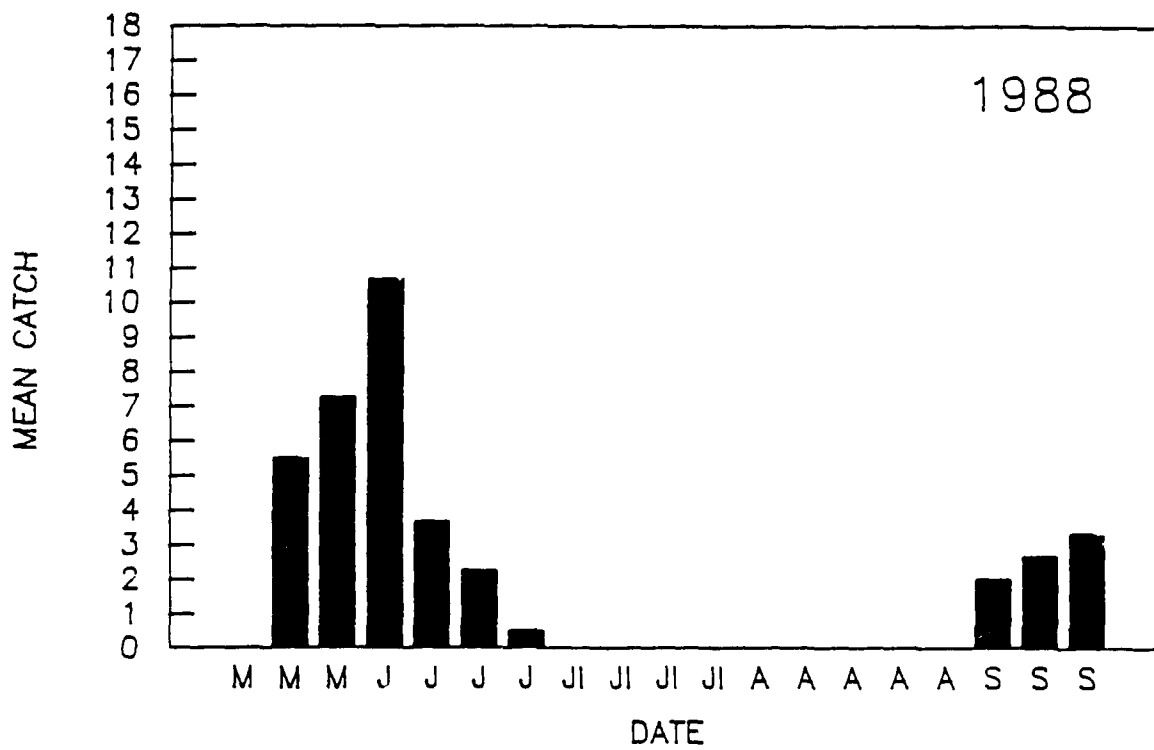


Figure 8.1c. Mean daily catch of brook trout plotted on a weekly basis at FCD from 1988.

The 1985 annual report discussed in detail the relationship between temperature and movement in 1984 and 1985. This movement was not repeated in 1986 although temperatures did exceed 16 C which is the optimal growth temperature for brook trout. An analysis of the pattern of water temperatures for each year shows that temperatures in 1984 and 1985 rose rapidly and remained high (Figure 8.2). Water temperatures in 1986, although not significantly different from 1985 (Freidman's Test with multiple comparisons,  $p>0.05$ ), demonstrated a cyclic nature with gradual increases to the two peaks. The pattern in 1987 water temperatures was similar to 1984 through mid-July, with the same rapid rise in temperature seen in June. Significant differences in temperature were found between 1937 and all other years (Freidman's Test with multiple comparisons,  $p>0.05$ ). The rapid rise and maintenance of high temperatures through July were the main differences between 1987 data and the 1984-85 data. During the drought of 1988, temperatures increased even more rapidly than in 1987, exceeding the optimum by the last week of May. 1988 temperatures also remained suboptimal for a longer period of time; extending through late August. Differences in the 1986-87 data can be attributed to the rapid cooling in late July-August. 1988 differences can be associated with the spring/summer drought and below normal snowpack in the watershed. This indicates that the duration of high water temperatures and the acclimatization time to those temperatures may also play important roles in determining whether the brook trout move to more suitable habitats.

Two additional factors, although not significant in the 1985 analysis of factors, which influence this movement were discharge and population size. The spring drought created extremely low water conditions in 1986 and 1988. Comparisons between years shows that 1986 and 1988 had significantly lower discharge than the other years (Freidman's Test with multiple comparisons,  $p<0.05$ ) and is illustrated in Figure 8.3a and b. Results from 1987 were also significantly lower than for 1984 and 1985 (Freidman's Test with multiple comparisons,  $p<0.05$ ). Rains in July increased discharge to a normal level but came too late, after the critical movement period. These low water conditions coupled with poor groundwater inputs to the river from low spring precipitation may have created a thermal barrier to this movement in 1986 although conditions were not as severe as in 1987 and 1988. The low water conditions and poor snowpack in these two years coupled with high temperatures caused a rapid rise in temperatures which was not mitigated by ground water inputs. These situations were similar to that seen in 1984 and forced brook trout to find other thermal refugia. In 1986, low densities of brook trout may have also contributed to the lack of movement by

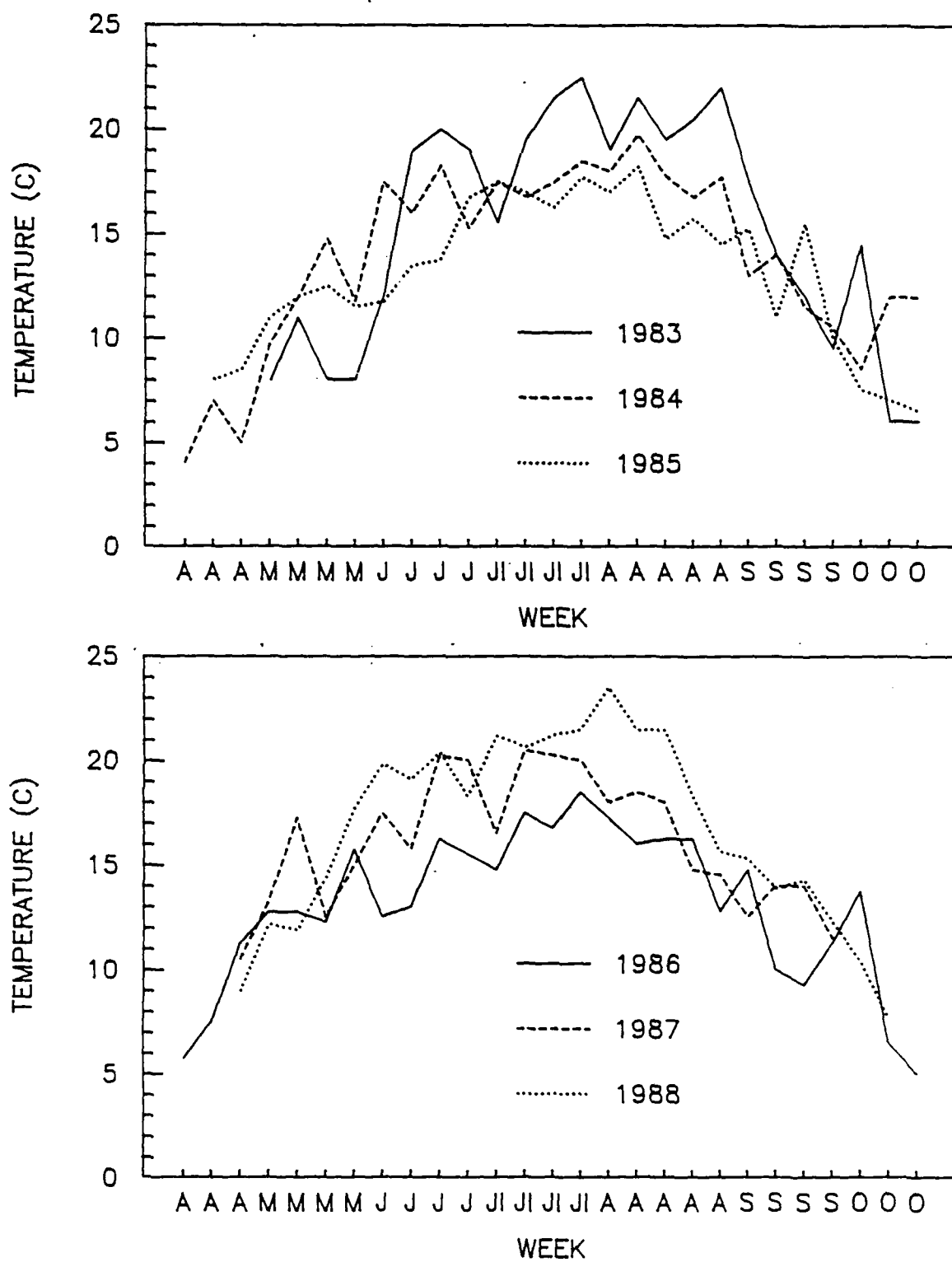


Figure 8.2. Mean daily temperature (C) plotted on a weekly basis at FCD from 1983 to 1985 and from 1986 to 1988 respectively.

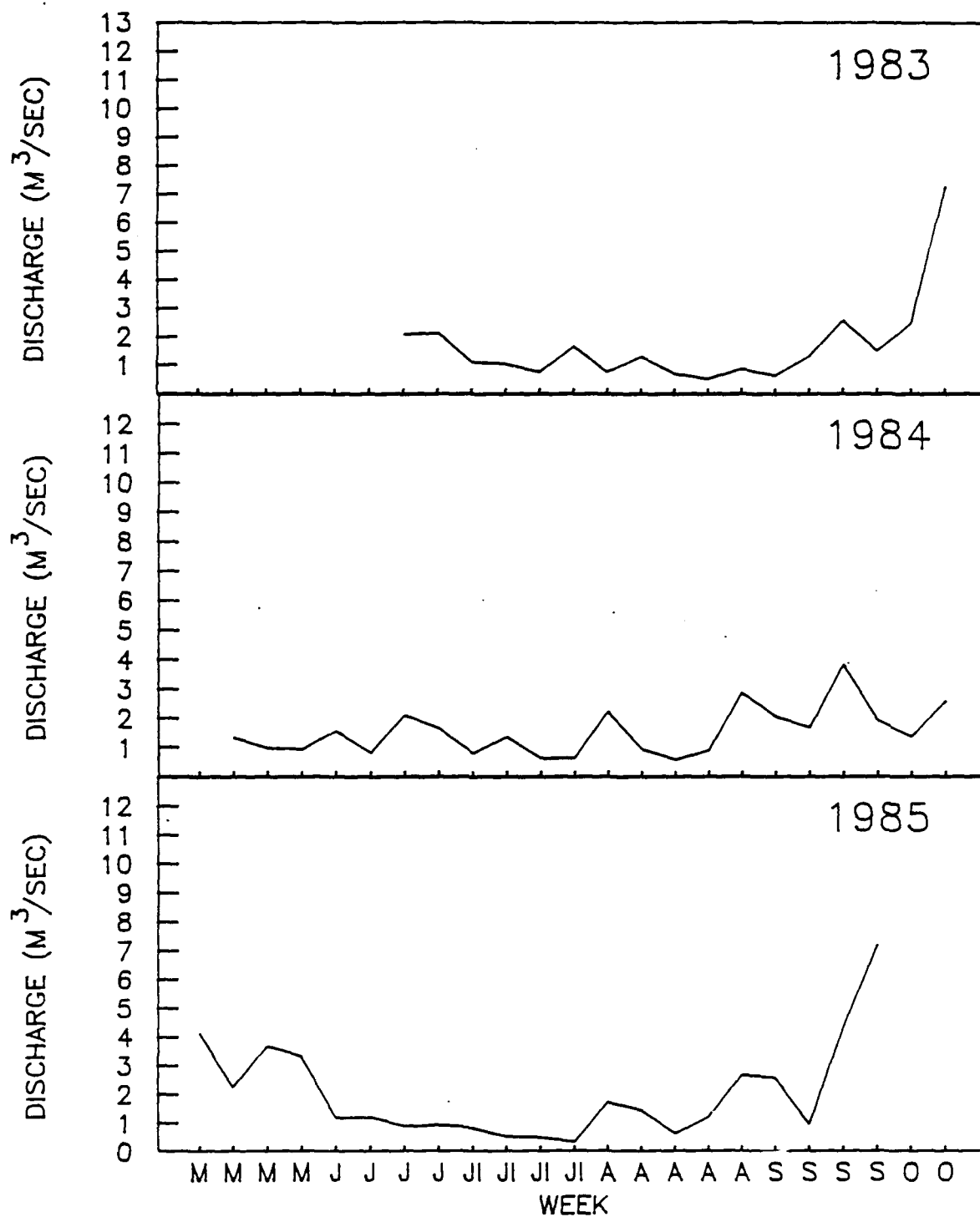


Figure 8.3a. Mean weekly discharge (m<sup>3</sup>/sec) at FCD from 1983–1985.

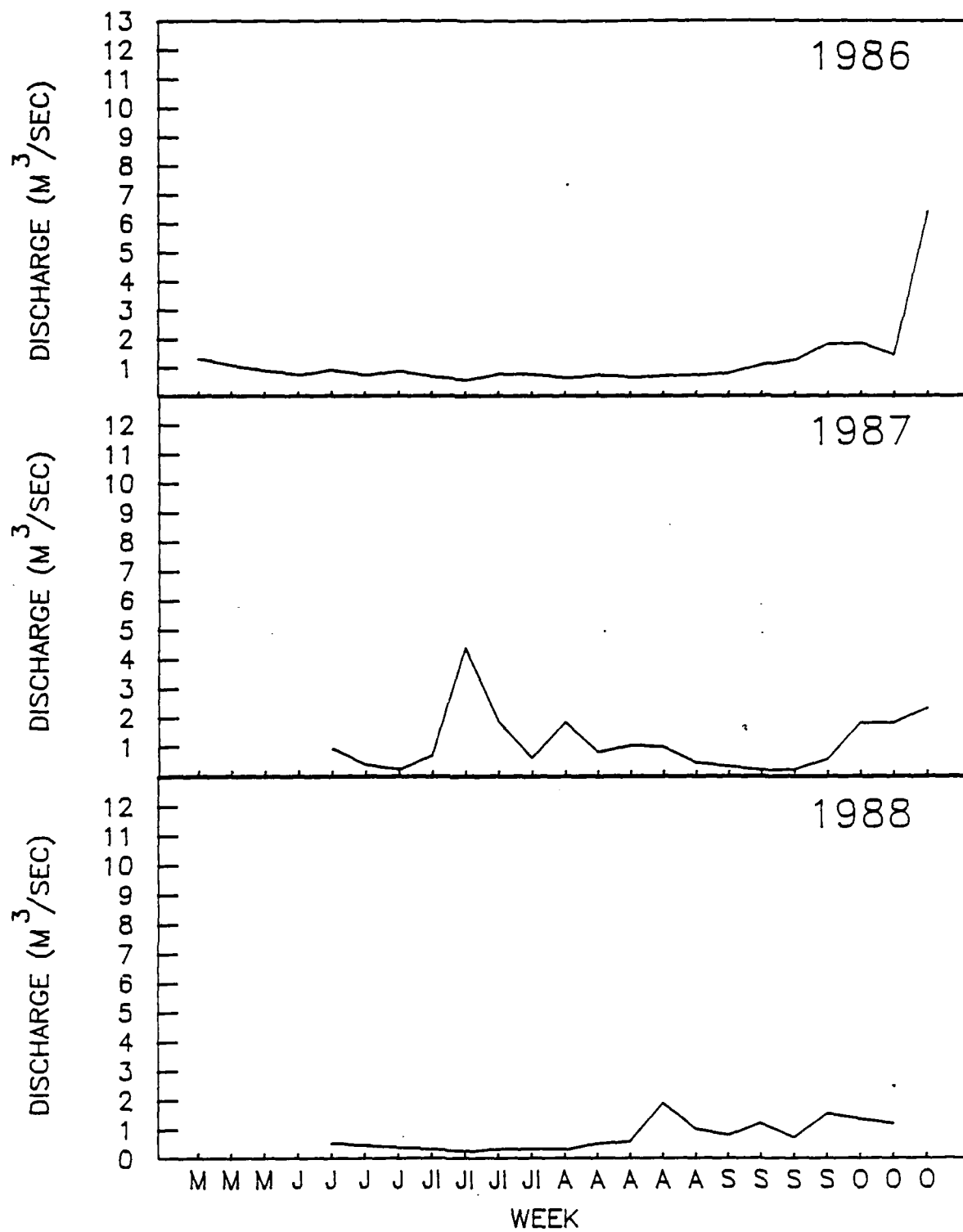


Figure 8.3b. Mean monthly discharge (m<sup>3</sup>/sec) at FCD from 1986–1988.

allowing those fish impacted by high temperatures to find available cold groundwater refugia without competition from other salmonids. In 1987 and 1988, the conditions were more extreme as in 1984 and the fish responded by moving. Additional analyses examining discharge and movement are currently in progress and will be discussed in a future report.

#### C. Brook Trout Movement Characteristics

In general, brook trout moved from FEX and FCD upstream to the TM site on Two Mile Creek based on both gear recapture and usable angler data (Table 8.3). Only one fish was recaptured at FCU in three sampling seasons. No downstream movement from Two Mile Creek has been found from 1984 through 1988 during the summer sampling period. Three tag loss fish from the TM site in 1984 were collected in 1985 at FCD, thus some return movements occurred between winter and early spring. The length of the brook trout that made this movement was significantly greater for fish above 190 mm than those below 190 mm (Chi-Square Test,  $p < 0.05$ ). Only six clipped fish under 190 mm were captured at TM in 1984 and no clipped fish under 190 mm were collected through 1988.

From a bioenergetic standpoint, optimal growth temperatures appeared to be responsible for the movement up Two Mile Creek instead of continuing up the Ford River. Groundwater inputs kept TM at or near 16 C during the period from 1984 to 1986 and 1988 (Figures 8.4 a and b). Reduced groundwater inputs (Figure 8.5) did force temperatures higher in 1987 than in previous years. Little difference in temperature was seen in 1987 between FCU and TM which can be attributed to the poor snowpack and drought which prevented the groundwater from being recharged. FCU exceeded the temperatures in TM in each field season thus the fish "chose", when the thermal difference was available, the tributary that they could maintain better growth and survival in.

#### D. Brook Trout Movement Rates

The rates of brook trout movement, like direction, have the potential to be a very sensitive indicator of ELF effects. If trout have difficulty orienting through ELF wavelengths, we would expect to observe decreased movement rates, especially near the antenna. Brook trout were found to move at mean rates of between 1.1 to 5.0 km/day (Table 8.3). Fish moving from FEX to TM (12.7 km) moved at similar rates from 1.4 to 1.8 km/day in 1984, 1985 and 1987. No movement was found between FEX and TM in 1986. Movement from FCD to TM (26.8 km) occurred at different mean rates in

Table 8.3. Brook trout movement rate summary for 1984 through 1988.

Year	Recapture Type	Site Marked to Site Recaptured	Distance (km)	N	Mean Rate (km/day $\pm$ 1SD)	Mode (km/day)
1984	Recaptured Fish	FEX- TM	12.7	11	1.4 $\pm$ 0.9	1.2
		FCD- TM	26.8	39	2.9 $\pm$ 1.7	2.5
		FCD-FEX	14.1	7	2.7 $\pm$ 1.6	2.0
	Angler Returns	FEX	7.0	1	2.5	
		FCD	14.4 $\pm$ 9.0	18	2.4 $\pm$ 2.6	1.3
1985	Recaptured Fish	FEX- TM	12.7	7	1.6 $\pm$ 0.9	1.1
		FCD- TM	26.8	6	5.0 $\pm$ 3.2	4.2
		FCD-FEX	14.1	3	1.2 $\pm$ 0.3	1.3
	Angler Returns	FCD	8.7 $\pm$ 9.9	3	1.1 $\pm$ 1.1	1.0
	No Recaptures or Angler Returns					
1987	Recaptured Fish	FEX- TM	12.7	1	1.8	1.8
	Angler Returns	FCD-FS1	19.1	1	3.8	3.8
1988	Recaptured Fish	FCD-FEX	14.1	2	2.3 $\pm$ 0.7	1.0
	No Angler Returns					

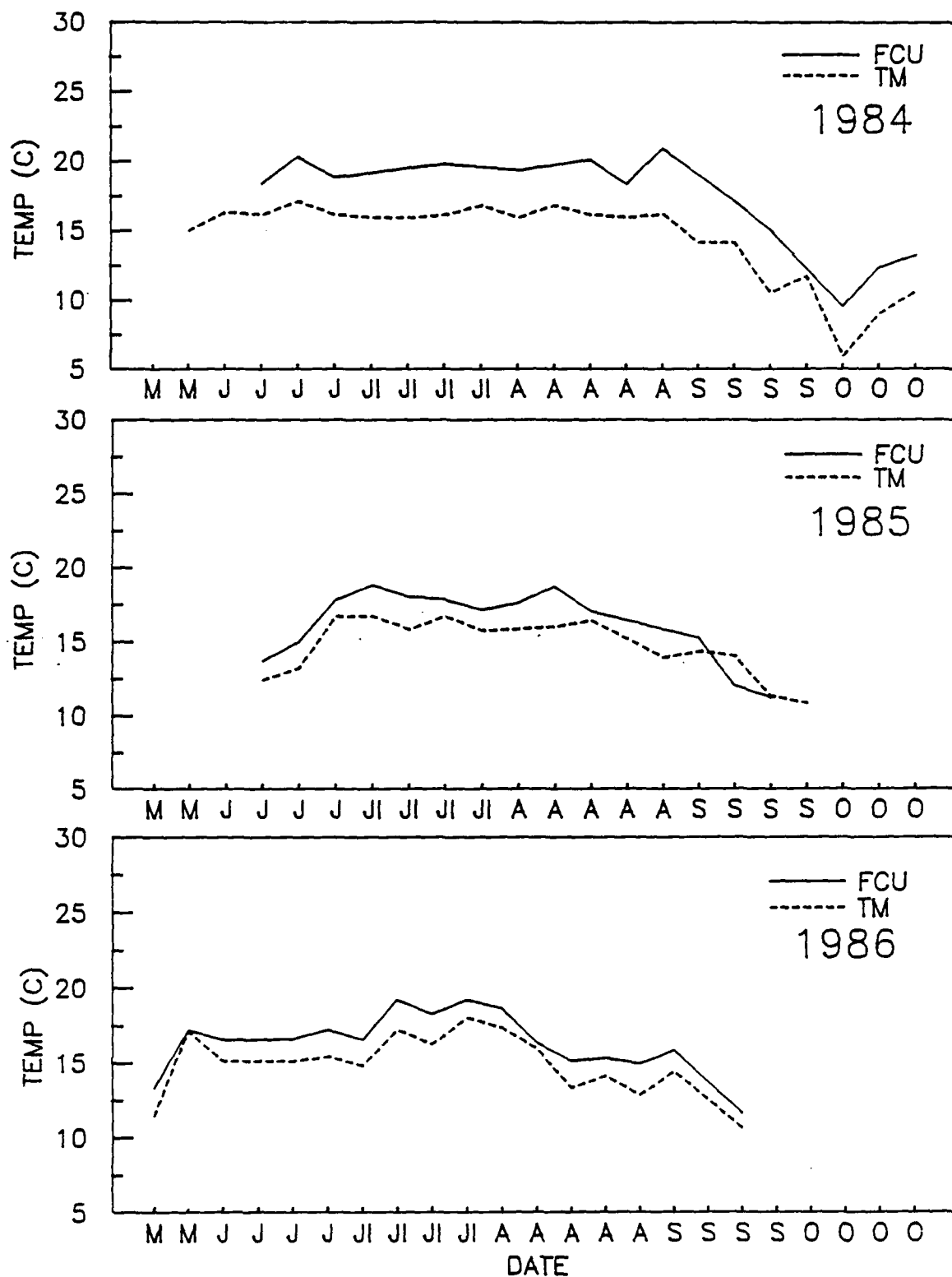
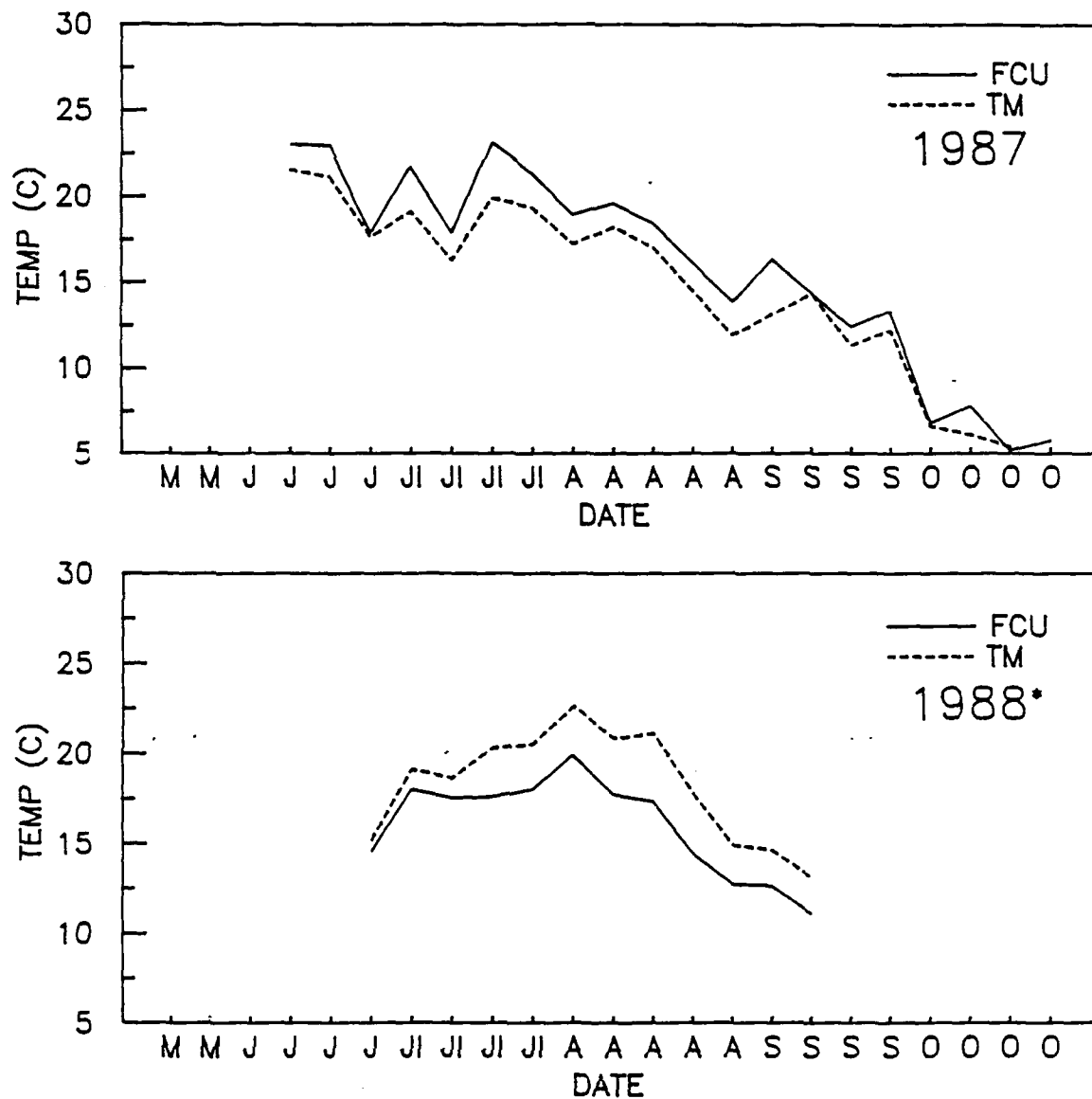


Figure 8.4a. Mean daily water temperature (C) plotted on a weekly basis at TM and FCU from 1984 to 1986.





\* Ryan thermographs used for mean temperatures in 1988.

Figure 8.4b. Mean daily water temperature (C) plotted on a weekly basis at TM and FCU from 1986 and 1987.

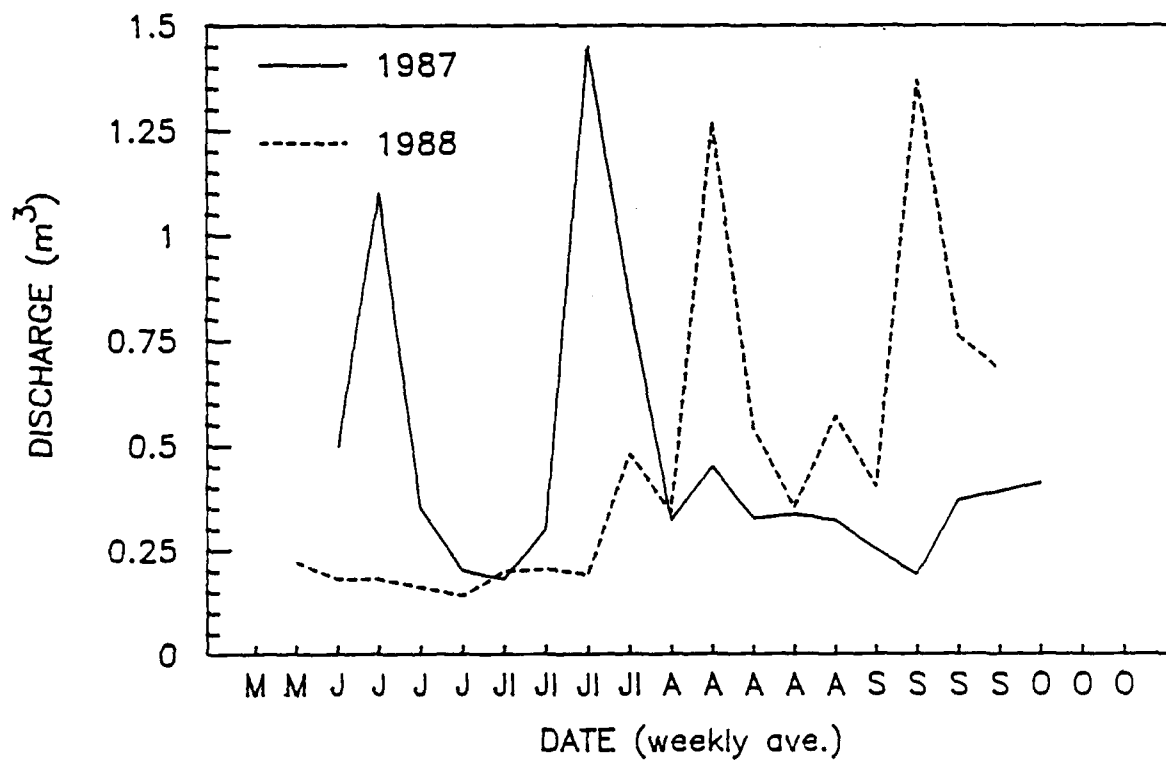
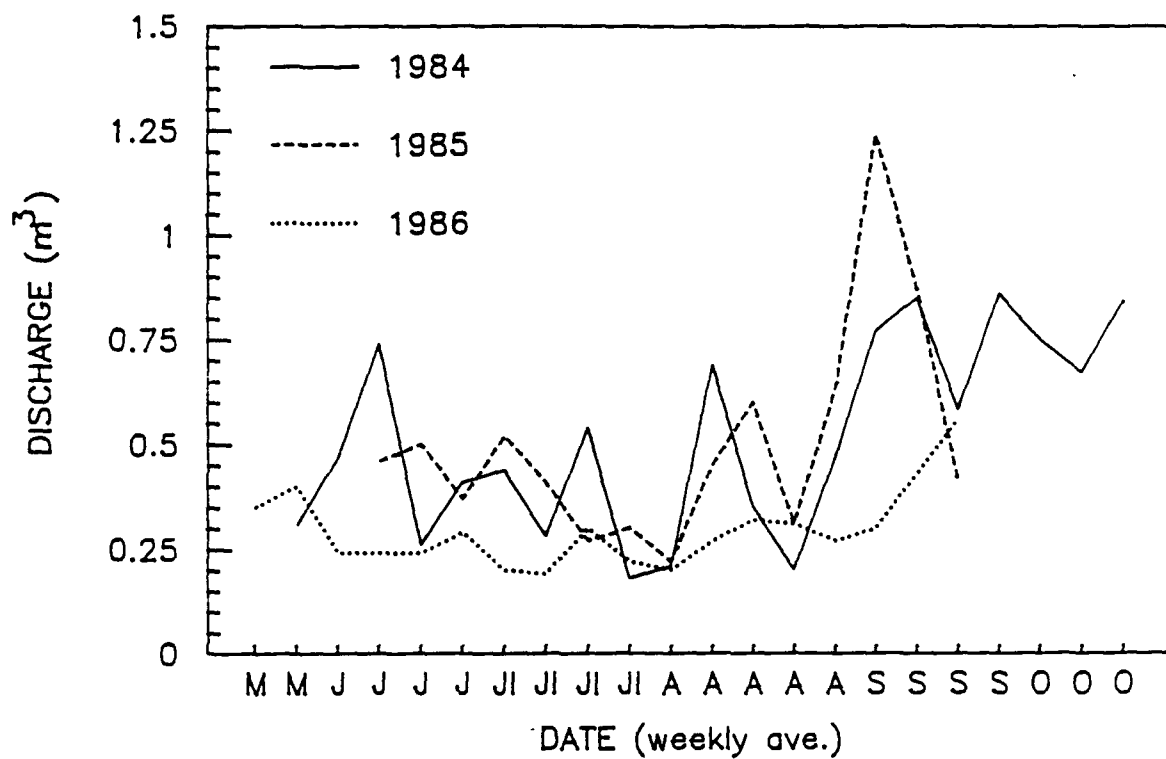


Figure 8.5. Mean weekly discharge at Two Mile Cr. from 1984 through 1986 and 1987 through 1988 respectively.

1984 (2.9 km/day) than in 1985 (5.0 km/day). No movement was found between FCD and TM in 1986-1988. Brook trout that were moving between FCD and FEX (14.1 km) also moved at different rates in the first two sampling years with rates of 2.7 km/day in 1984 and 1.2 km/day in 1985. No movement was observed between FCD and FEX in 1986 and 1987. In 1988 rates averaged 2.3 km/day between these two sites. Angler tag return data from throughout the Ford River verified the above trends and indicated that brook trout move at a steady pace (1984 - 2.4 km/day, 1985 -1.1 km/day and 3.8 km/day in 1987) upstream similar to rates recorded from our sampling gear.

MI DNR Population Analysis. Michigan Department of Natural Resources conducted four brook trout population surveys in 1985 and 1986 using 220 V DC electrofishing gear. Two sites were used in this analysis: 1) Ford Site 1 which is 5 km upstream from FEX; and 2) A site approximately 1 km upstream from FCD. Both sites were approximately 1000 m in length and 1 ha in area. A single Peterson mark-recapture estimate was done at each site to determine trout densities.

Ford Site 1 was found to have  $269 \pm 47.5$  fish per ha on June 25, 1985. The total biomass of this population was estimated from length frequency and length-weight data to be 2.35 kg/ha. The length frequency of this site showed that this area is mainly inhabited by young of the year fish with very low densities of adult and juvenile fish (Figure 8.6a).

Surveys of brook trout populations at the site near FCD showed very low densities of fish. Only 18 fish were caught on the marking run on June 27, 1985, 5 fish on the marking run on August 20, 1985 and 0 fish on the marking run on August 21, 1986. Population estimates were made from the one marking run by assuming that the catch efficiency of each size class was the same at both sites. Densities on June 27, 1985 were estimated at 60.7 fish/ha at FCD with a biomass of 1.28 kg/ha. The length frequency of the catch at this date shows very low densities of YOY and adult fish at the site (Figure 8.6b). No fish were captured in August 1986.

These preliminary data indicate that most brook trout move out of the lower site in the summer and are at low densities throughout the river. These densities are very low when compared to literature studies of brook trout populations and are probably indicative of the variable abiotic conditions in the Ford River. These data will be combined with 1988 DNR surveys and all available historical DNR data to provide additional baseline data. This data will also determine what percentage of the population moves in the Ford River.

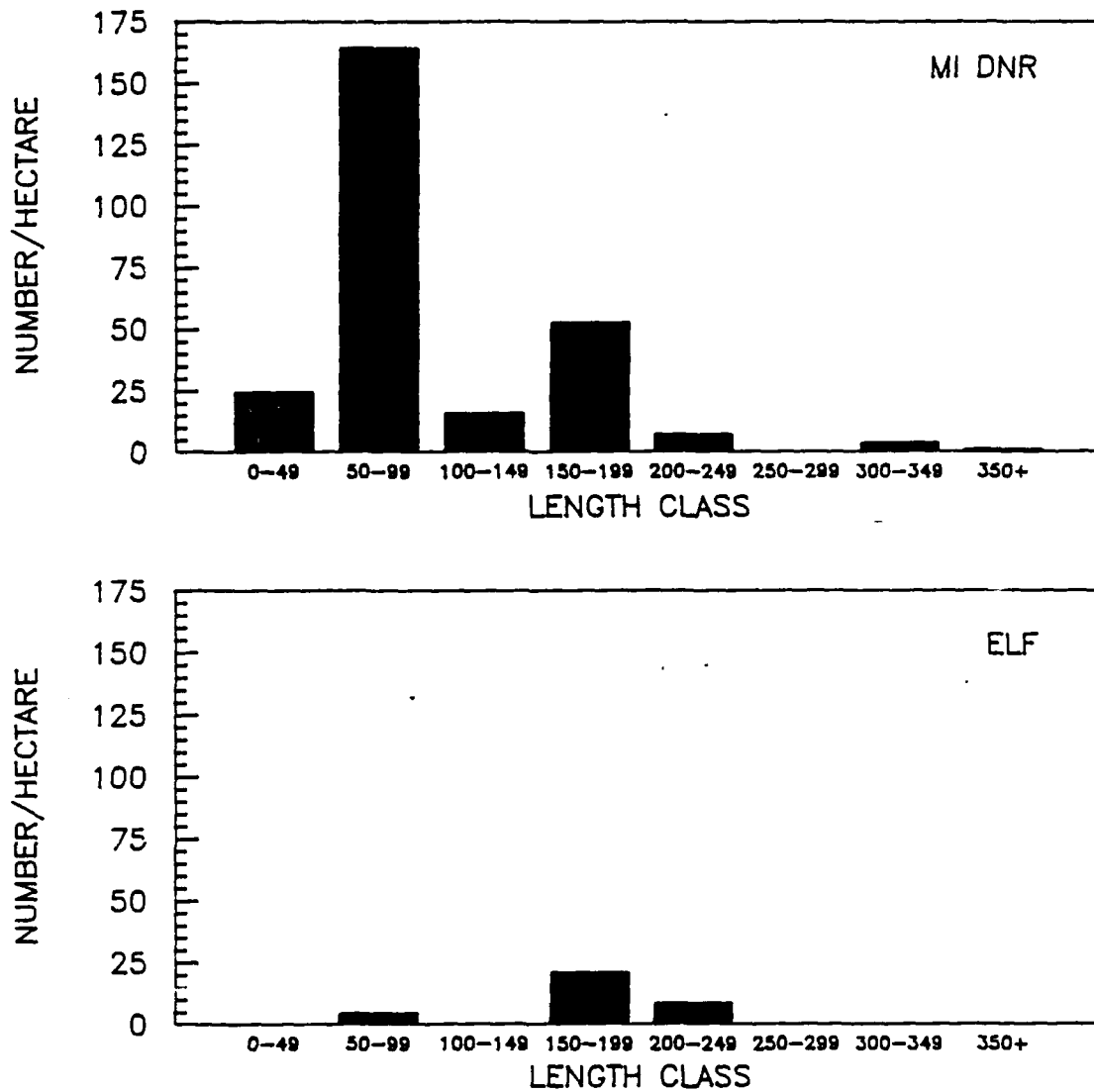


Figure 8.6a. Length frequency of brook trout at FS1 taken by MI DNR on 6-25-85 and MSU ELF personnel on 9-14-87.

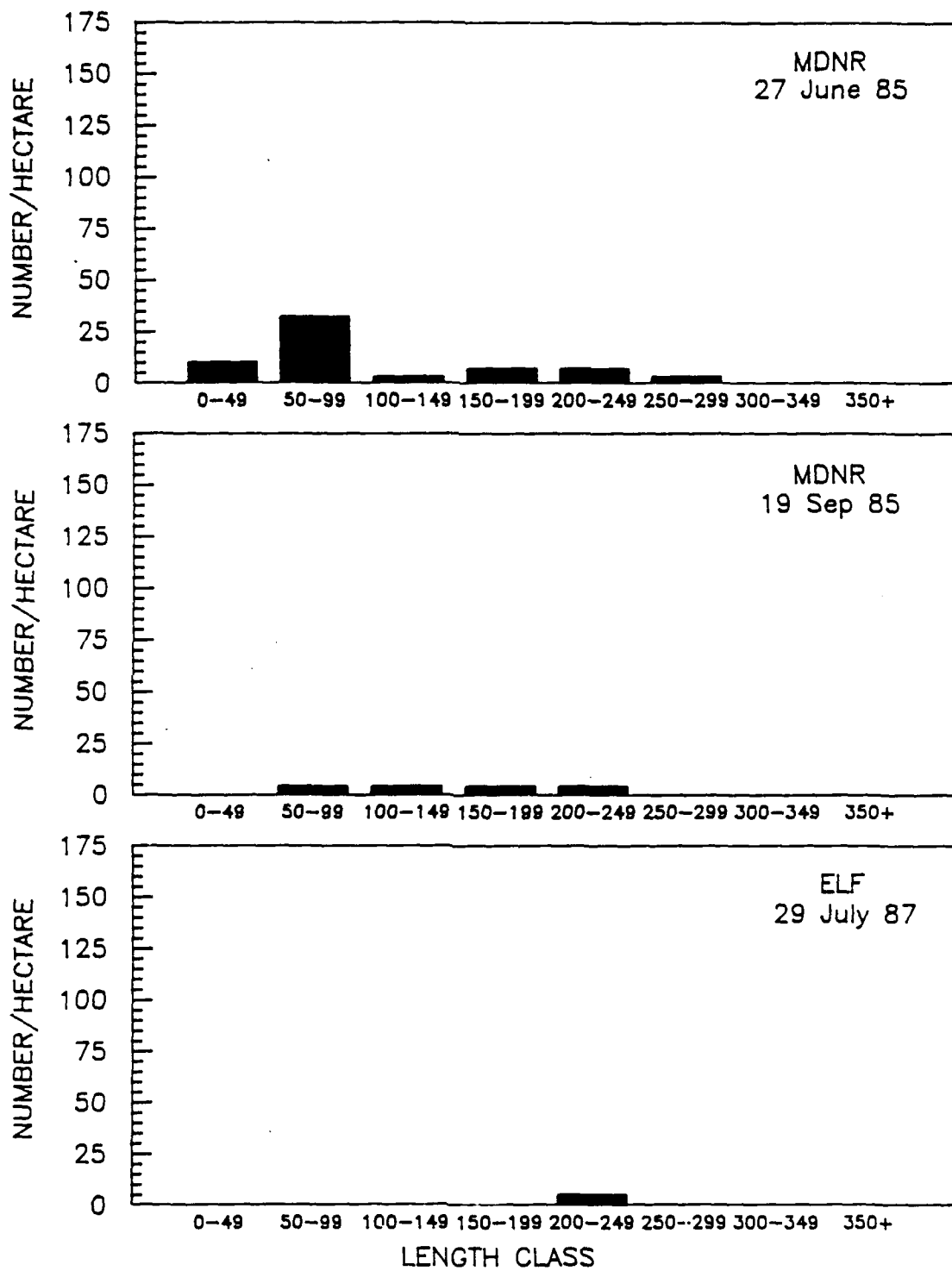


Figure 8.6b. Length frequency of brook trout taken by MI DNR and ELF personnel at FCD. Dates are included on graphs.

ELF Population Estimates. ELF study 1987 DeLury brook trout estimates ranged from 4.2 fish/HA at FCD to 364.3 fish/HA at TM (Table 8.4). Biomass estimates ranged from 0.3 Kg/HA at FCD to 10.3 Kg/HA at TM. Length frequency values at FCD, FEX, FSI and FCU mirrored MI DNR values and were primarily yearling to adult fish (Figures 8.6a-e) whereas Two Mile Cr. was predominantly YOY and yearling fish (Figure 8.6f).

In 1988, pre-movement (May) and post-movement (late June-early July) DeLury estimates were obtained at all sites. Pre-movement estimates ranged from 41.3 fish/HA (2.08 kg/HA) at FCD to 405.1 fish/HA (14.69 kg/HA) at Two Mile Creek. Post-movement estimates ranged from 0.0 fish/HA at FCD to 291.1 fish/HA (5.40 kg/HA) at Two Mile Cr. Pre-movement biomass estimates were higher than post-movement estimates at all sites (Table 8.4). Length frequency data also shows a higher number of yearling to adult fish were present during pre-movement than post-movement at all sites. Post-movement estimates consisted primarily of YOY and yearling individuals (Figures 8.6c-f). This is especially evident at FCU where the post-movement estimate of 283.6 fish/HA on 29 June, 1988 was higher than the pre-movement estimate of 209.0 fish/HA on 27 May, 1988. However, the post-movement biomass, 1.85 kg/HA, was lower than the pre-movement biomass of 3.48 kg/HA (Table 8.4) because there were fewer adult fish present. At Two Mile Cr., both numbers and biomass were highest during pre-movement which indicates that yearling - adult trout may flee even the lower sections of the creek and seek refuge even further upstream into Weber Cr. and the upper Two Mile (Table 8.4).

An early fall estimate was also obtained at FCD and Two Mile Cr. Where FCD estimates showed no change from post-movement estimates, the Two Mile Cr. population and biomass on 9 September, 1988, increased back to pre-movement levels (Table 8.4). This probably indicates temperatures in the stream have returned to optimal and fish are beginning to stage for the late September early October spawning migration.

The study plan for 1989 calls for the same pre- and post-movement estimates and when combined with MI DNR data will provide a baseline data set to utilize to test ELF effects. Additional analyses being considered are an examination of mortality rates, length frequencies, and site habitat differences.

#### F. Brook Trout Age and Growth

Age and growth analysis on brook trout was completed using fish captured in the fyke nets and weirs. Data for all sites was pooled because of the high amount of mobility brook trout display in the Ford River. Age determination

Table 8.4. DeLury population estimates ((density (num/ha), biomass (kilogram/ha)) for brook trout at all sites from 1987 and 1988.

Site	Date	Lower 95% CI	Estimate	Upper 95% CI	Biomass
FEX	870701	0.0	16.7	36.3	1.56
	870826	40.8	41.7	42.5	1.73
	880523	50.5	64.2	120.2	1.75
	880714	37.2	45.9	54.6	1.25
FCD	850627		60.7		1.28
	850820		35.0		
	860821		0.0		
	870727		4.2		0.32
	870829		4.2		0.28
	880524	33.0	41.3	85.5	2.08
	880707		0.0		
	880826		0.0		
FCU	870818	97.0	122.2	147.5	4.71
	880527	176.1	209.0	241.8	3.48
	880629	249.3	283.6	317.9	1.85
TM	870817	265.0	364.3	463.4	10.30
	880525	284.8	405.1	617.1	14.69
	880630	263.3	291.1	319.0	5.40
	880909	329.1	341.8	387.3	11.17
FS1	850625		269.0		2.35
	870914	32.3	34.4	34.4	1.83

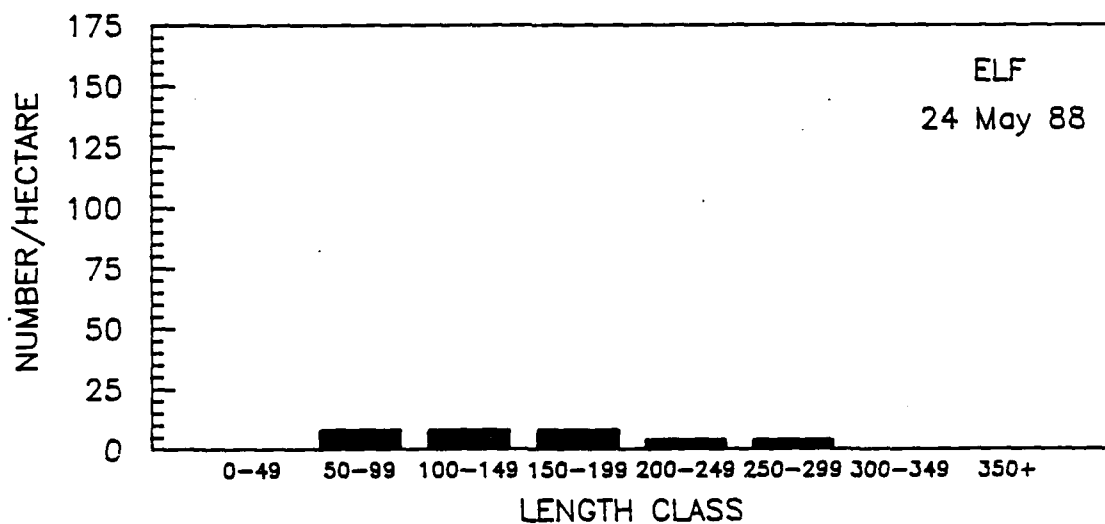
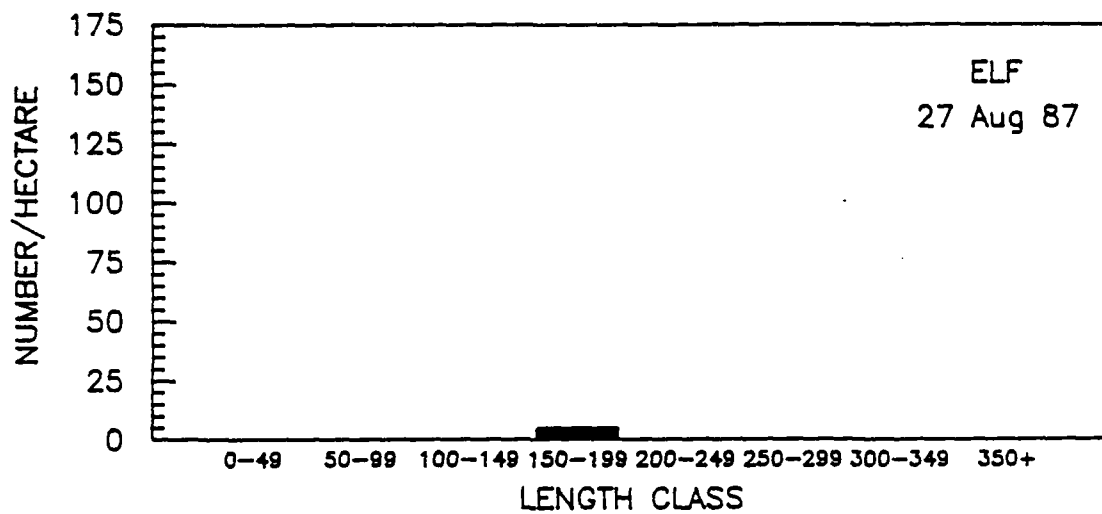


Figure 8.6c. Length frequency of brook trout at FCD taken by ELF personnel.



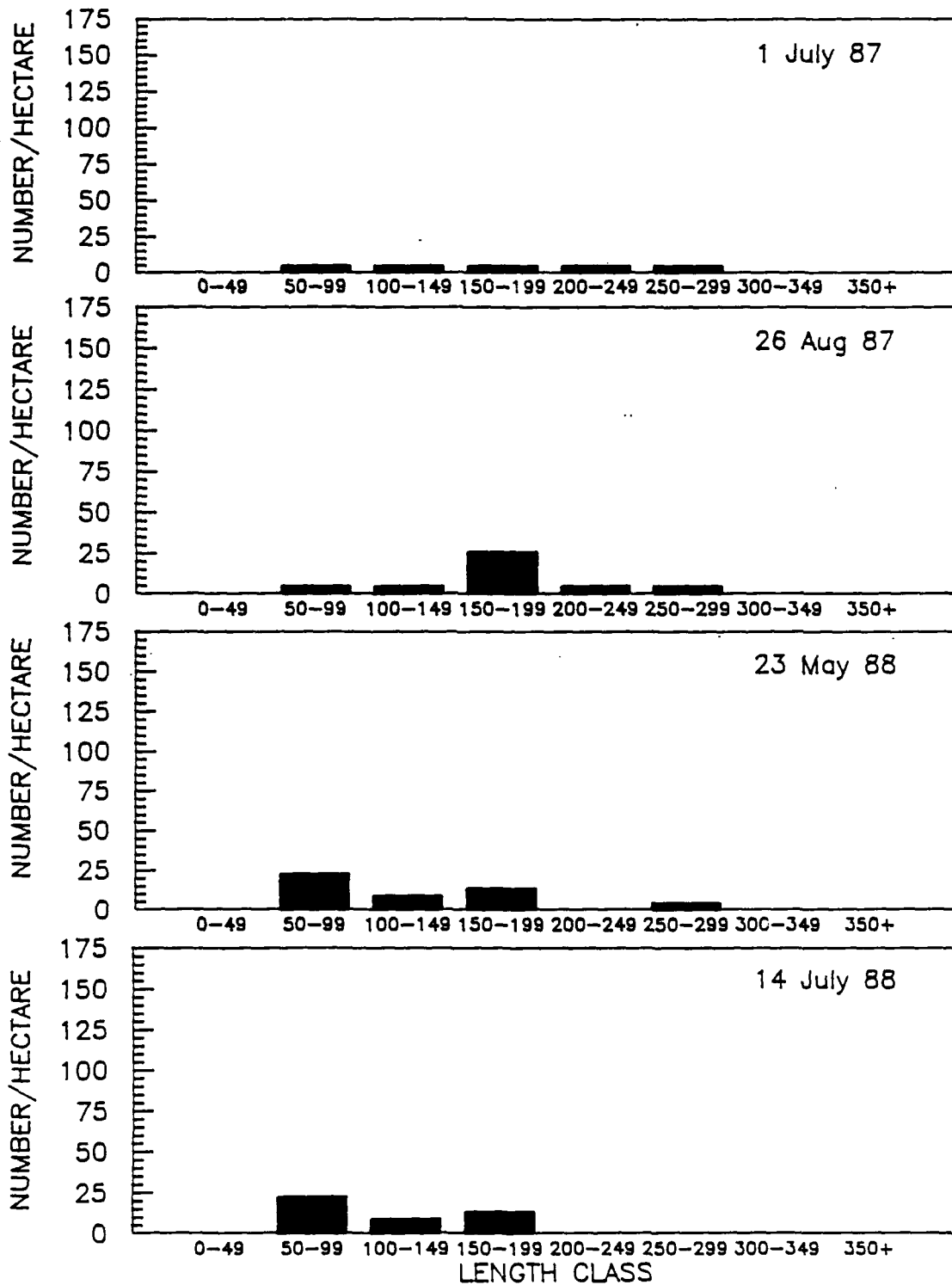


Figure 8.6d. Length frequency of brook trout taken by ELF personnel at FEX.

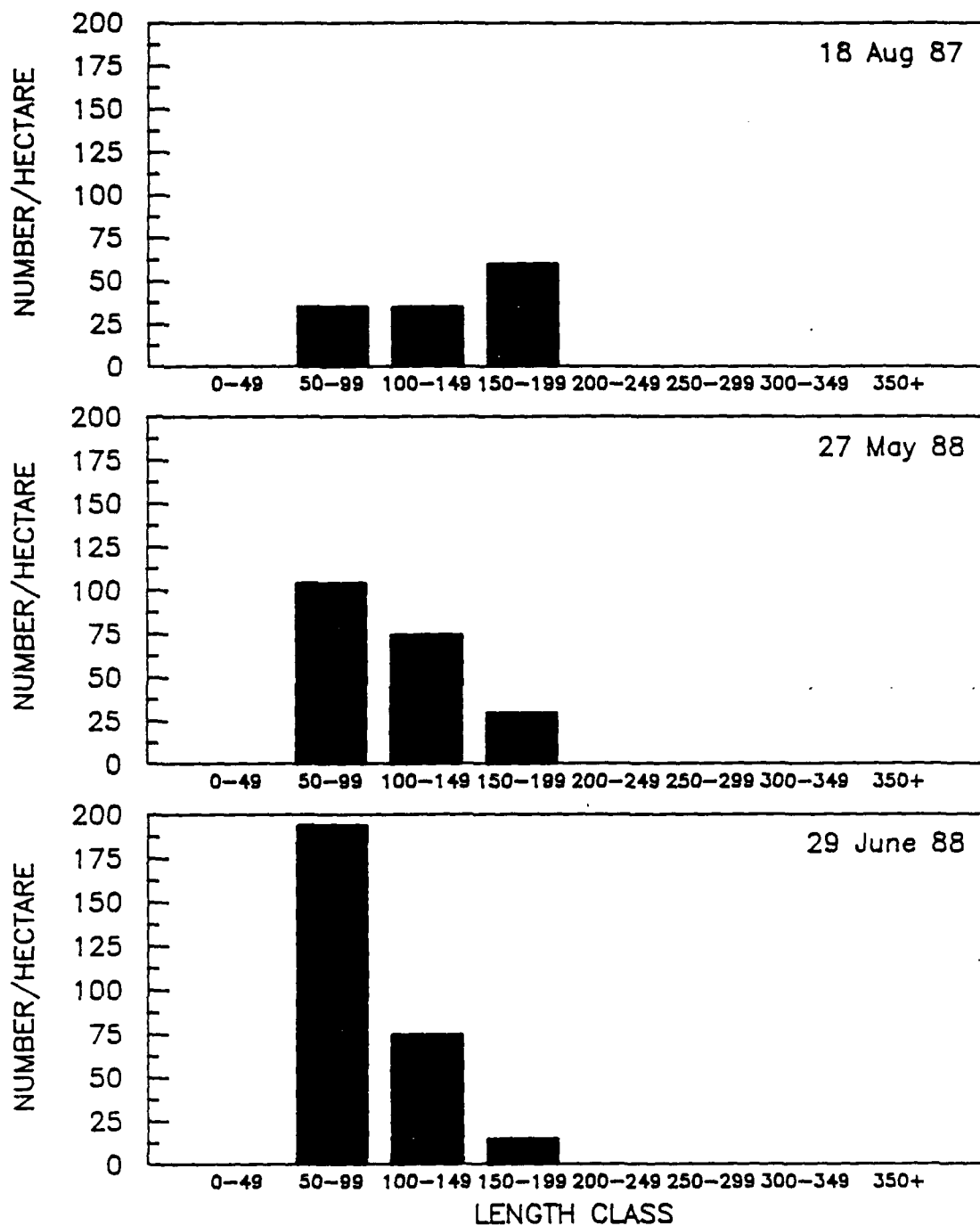


Figure 8.6e. Length frequency of brook trout taken by ELF personnel at FCU.

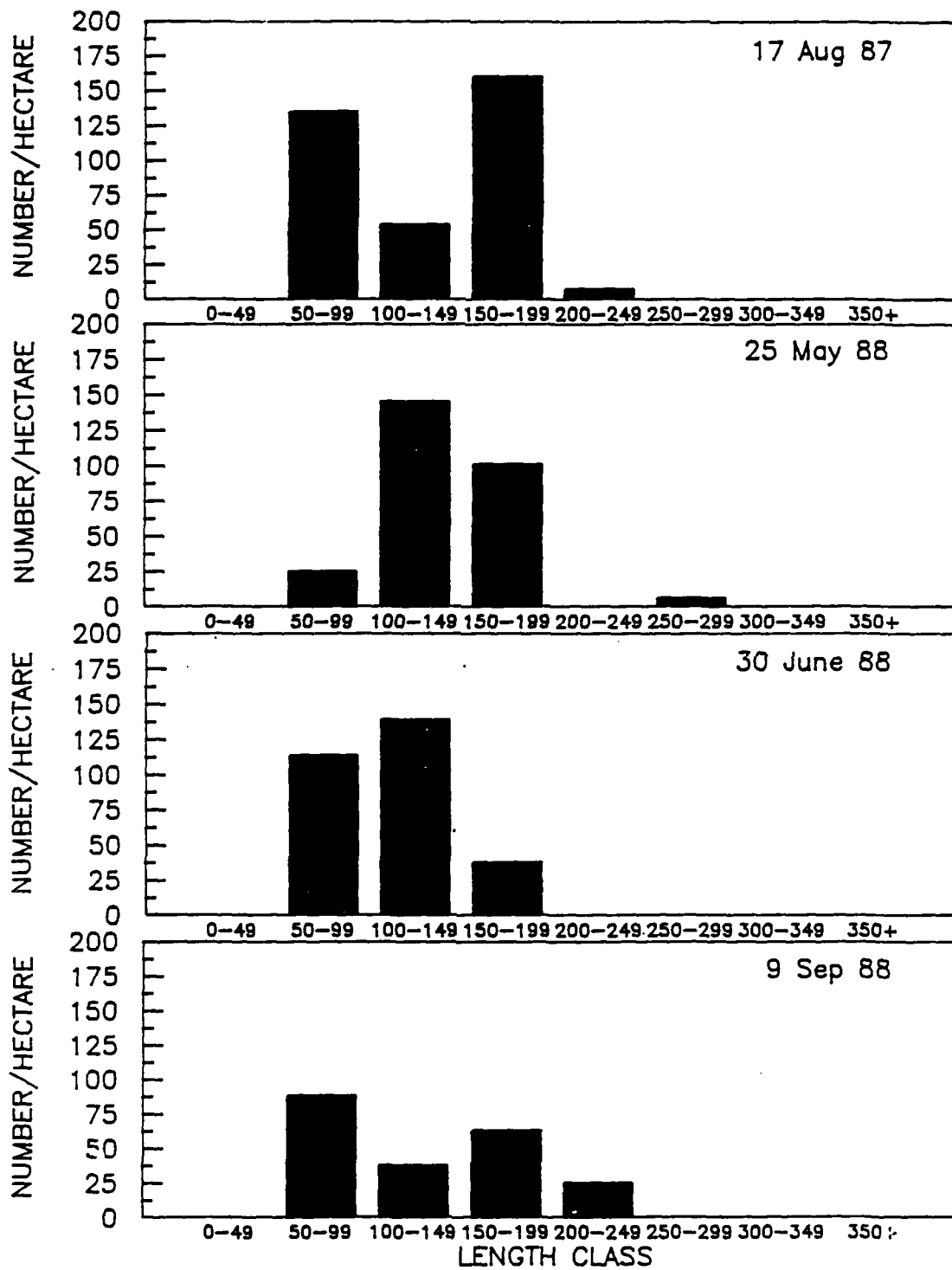


Figure 8.6f. Length frequency of brook trout taken by ELF personnel at Two Mile Cr.

was done using scales. The body-scale relationship was determined using the technique described in Smale and Taylor (1987). Backcalculations were made using the linear technique described in Bagnenal and Tesch (1978).

Ford River brook trout show excellent growth as seen in Table 8.5 when compared to populations described in Carlander (1969). Size at annulus formation was consistent from 1983-88. Lee's phenomena was not seen in any year. Statistical analysis of yearly differences and comparisons to the literature are in progress and will be included in a future report. These growth parameters will be a key to defining any significant ELF effects. We expect to see decreased growth in trout inhabiting the mainstream if they are forced to endure chronic exposure to warmer water temperatures. This will occur if fish are delayed in their migration or excluded from refuge areas.

#### G. Brook Trout Condition

Examination of brook trout condition was made using the relative weight methodology as described in element 7. The standard weight formula:

$$\log wt = -5.085 + 3.043 * \log tl \quad (r=.999)$$

was determined using the 50th percentile equation from 45 populations reported in the literature.

Brook trout relative weight ranged from average to slightly below average from 1983 to 1988 compared to values obtained from the above equation (Figure 8.7). Relative weight values declined from 101.6 in 1983 to 89.0 in 1986. Condition improved in 1987 to 92.6 and maintained that level in 1988. This value is still below the condition values found from 1983-85. Low water conditions, above optimal temperatures and poor groundwater inputs may have caused the decline from the 1984-1985 values to the lower 1986-1988 values. Statistical analysis of yearly and seasonal trends is in progress and will be reported on in an upcoming report.

Table 8.5. Backcalculated length ( $\pm$  standard deviation) at annulus data for brook trout from 1983-1988. Values in () are sample size.

Age Class	Backcalculated Length at Annulus		
	1	2	3
1	90 $\pm$ 19.6 (339)		
2	80 $\pm$ 22.1 (178)	188 $\pm$ 30.6 (178)	
3	85 $\pm$ 34.5 (15)	186 $\pm$ 44.0 (15)	280 $\pm$ 47.7 (15)
Overall Mean	87 $\pm$ 21.5 (532)	187 $\pm$ 31.7 (193)	280 $\pm$ 47.7 (15)

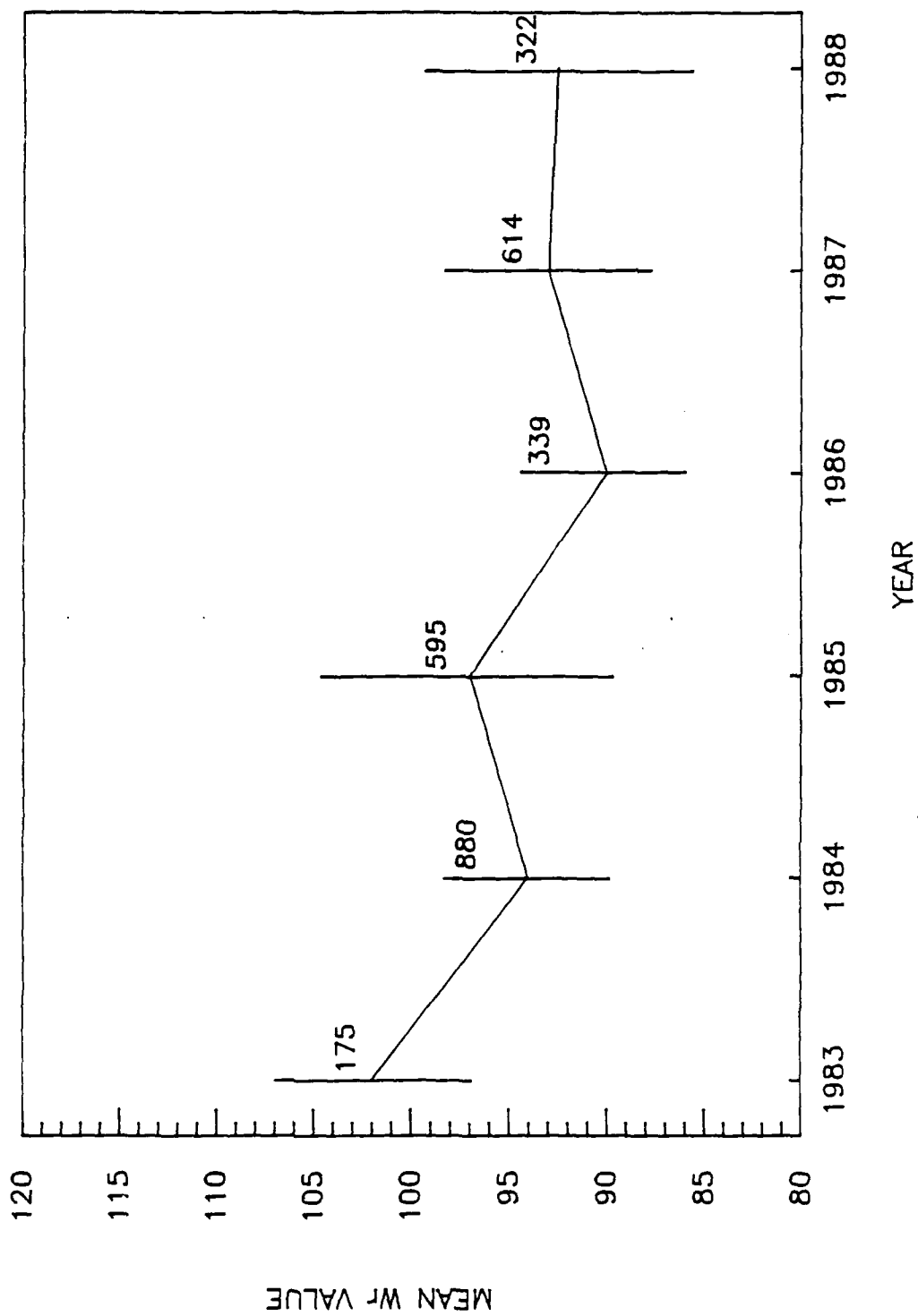


Figure 8.7. Brook trout mean ( $\pm$  SD) yearly  $W_r$  values from the Ford River.  
Numbers adjacent to means refer to sample size used in calculation.

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## APPENDIX I

### List of Taxa of Aquatic Insects From FEX and FEX, Ford River

#### EPHEMEROPTERA

##### TRICORYTHIDAE

Tricorythodes Ulmer

##### CAENIDAE

Drunella cornutella McDunnough

Dannella simplex McDunnough

Ephemerella invaria (Walker)

E. needhami McDunnough

E. rotunda Morgan

E. subvaria McDunnough

Serratella deficiens (Morgan)

S. sordida (McDunnough)

Eurylophella bicolor (Clemens)

##### BAETIDAE

Baetis flavistriga McDunnough

B. vagans McDunnough

B. macdunnoughi Ide

B. pygmaeus (Hagen)

Pseudocloeon parvulum McDunnough

P. punctiventris (McDunnough)

Centropilum cf. rufostrigatum McDunnough

##### OLIGONEURIIDAE

Isonychia Eaton

##### SIPHONURIDAE

Siphonorus rapidus McDunnough

##### LEPTOPHLEBIIDAE

Paraleptophlebia mollis (Eaton)

Leptophlebia cupida (Say)

##### HEPTAGENIIDAE

Epeorus vitrea (Walker)

Rhithrogena jejuna Eaton

Stenonema vicarium (Walker)

S. modestum (Banks) (= S. rubrum McDunnough)

S. exiguum Travel (= S. quinquespinum Lewis)

S. pulchellum (Walsh)

Leucrocuta hebe (McDunnough) (= Heptagenia hebe)



Nixe lucidipennis (Clemens) (= Heptagenia lucidipennis)  
Stenacron interpunctatum (Say)

BAETISCIDAE

Baetisca laurentina McDunnough

EPHEMERIDAE

Ephemera simulans Walker  
Hexagenia limbata (Serville)

ODONATA

GOMPHIDAE

Ophiogomphus colubrinus Selys  
O. carolus Needham  
Gomphus (Stylurus) scudderi Selys  
G. (Gomphus) lividus Selys  
Dromogomphus spinosus Selys  
Hagenius brevistylus Selys

AESCHNIDAE

Boyeria vinosa Say

CORDULEGASTERIDAE

Cordulegaster maculatus Selys

CALOPTERYGIDAE

Calopteryx sp. Leach

PLECOPTERA

CAPNIIDAE

Allocapnia Claassen  
Paracapnia Hanson  
Capnia Pictet

CHLOROPERLIDAE

Haploperla Navas  
Alloperla Banks  
Suwallia Ricker

PERLIDAE

Acroneuria lycorias (Newman)  
A. abnormis (Newman)  
Paragnetina media (Walker)

PERLODIDAE

Isogenoides Klapalek  
I. olivaceous (Walker)  
Isoperla transmarina (Newman)  
I. slossonae (Banks)

NEMOURIDAE

Amphinemura Ris  
Paranemoura (Walker)

PTERONARCIDAE

Pteronarcys Newman

TAENIOPTERYGIDAE

Taeniopteryx nivalis (Fitch)

HEMIPTERA

BELOSTOMATIDAE

Belostoma flumineum Latreille  
Lethocerus Mayr

TRICHOPTERA

BRACHYCENTRIDAE

Brachycentrus numerosus (Say)

GLOSSOSOMATIDAE

Glossosoma intermedium (Klapalek)  
G. nigrrior (Banks)  
Protoptila tenebrosa (Walker)

LIMNephilidae

Anabolia Stephens  
Hydatophylax argus? Wallengren  
Platycentropus Ulmer  
Pycnopsyche subfasciata (Say)  
Neophylax nacatus Denning

HYDROPSYCHIDAE

Ceratopsyche morosa (befida form)  
C. sparna (Ross)  
Cheumatopsyche analis (Banks)  
Potamyia Banks

HYDROPTILIDAE

Hydroptila Dalman  
Leucotrichia pictipes (Banks)  
Neotrichia Morton  
Oxyethria Eaton

LEPIDOSTOMATIDAE

Lepidostoma Rambur

LEPTOCERIDAE

Oecetis avara (Banks)  
Ceraclea angustus (Banks)  
Trialenodes tarda Milne  
Mystacides Berthold  
Setodes incertus (Walker)

ODONTOCERIDAE

Psilotreta indecisa Banks

MOLANNIDAE

Molanna Curtis

PHILOPOTAMIDAE

Chimarra aterrima (Hagen)  
Dolophilodes distinctus (Walker)

PHRYGANEIDAE

Ptilostomis Kolenati

POLYCENTROPODIDAE

Neureclipsis crepuscularis (Walker)  
Nyctiophylax moestus (Banks)

PSYCHOMYIIDAE

Psychomyia flavida (Hagen)  
Lype diversa (Banks)

HELICOPSYCHIDAE

Helicopsyche borealis (Hagen)

COLEOPTERA

ELMIDAE

Ancyronyx variegata Erichson

Optioservus Sanderson  
O. fastiditus (Le Conte)  
O. trivittatus (Brown)  
Macronychus glabratus Say  
Dubiraphia Sanderson

DRYOPIDAE

Helichus lithophilus (Germar)

GYRINIDAE

Gyrinus Geoffroy in) Muller

DYTISCIDAE

Celina Aube  
Dytiscus harrisi Kirby  
Laccophilus Leach

HYDROPHILIDAE

Paracymus subcupreus (Say)

MEGALOPTERA

CORYDALIDAE

Nigronia Banks

SIALIDAE

Sialis Latreille

DIPTERA

DOLICHOPODIDAE

Rhaphium Meigen

EMPIDIDAE

Hemerodromia Meigen  
Clinocera Meigen  
Chelifera Macquart

BLEPHARICERIDAE

Blepharicera Macquart

TABANIDAE

Tabanus Linnaeus  
Chrysops Meigen

## TIPULIDAE

Antocha Osten Sacken  
Tipula Linnaeus  
T. abdominalis (Say)  
Hexatoma (erlocera) c.f. spinosa (Osten Sacken)  
Dicranota Zetterstedt  
Hesperoconopa Alexander

## CERATOPOGONIIDAE

Probezzia Kieffer  
Culicoides Latreille

## CHIRONOMIDAE

### TANYTARSINI

Tanytarsus van der Wulp  
Rheotanytarsus Theinemann and Bause  
Microspectra Kieffer  
Stempellinella Brundin  
Stempellina Thienemann and Bause

### TANYPODINAE

Ablabesymia Johannsen  
Pentaneura Philippi  
Thienemannimyia group (sensu Simpson & Bode, 1980)  
Labrundina Fittkau  
Procladius Skuse  
Procladius cf. sublettei Roback  
Nilotanypus Kieffer

## ORTHOCLADIINAE

Brillia flavifrons Johannsen  
Parametriocnemus Goetghebuer  
Corynoneura Winnertz  
Eukiefferiella Thienemann  
E. devonica group (sensu Lehman, 1972)  
E. claripennis group (sensu Bode, 1983)  
Rheocricotopus Thienemann and Harnisch  
Cricotopus van der Wulp  
Thienemanniella Kieffer  
Synorthocladius Thienemann  
Orthocladius (Eurthocladikus) Thienemann (in part)  
Ivetenia bavarica group (sensu Saether & Halvorsen, 1981)  
T. discoloripes group (sensu Saether & Halvorsen, 1981)  
Diplocladius Kieffer  
Lopescladius Olilveira  
Nannocladius Kieffer

Chaetocladius Kieffer  
Symptocladius Kieffer and Zavrel  
Heterotrissocladius marcidus (Walker)  
Xylotopus par (Coquillett)

#### CHIRONOMINI

Polypedilum cfd. lonvictum (Walker)  
P.cf. scalaenum (Schränk)  
P.cf. halterale (Coquillett)  
P.cf. aviceps Townes  
Robackia Saether  
R. demijerei (Krusemann, 1933)  
Microtendipes caelum Townes  
Stenochironomus Kieffer  
Cryptochironomus Kieffer  
Saetheria Jackson  
Parachironomus Lenz  
Chironomus Meigen  
Cryptotendipes Lenz  
Xenochironomus xenolabis Kieffer  
Paraleuterborniella Lenz

#### DIAMESINAE

Potthastia Kieffer  
Pagastia Oliver

#### ATHERICIDAE

Atherix variegata Walker

#### SIMULLIDAE

Cnephia mutata (Malloch)  
Simulium (Eusimulium) euryadminiculum Davies  
S. corbis Twinn  
S. quebecense Twinn  
S. venustum (Say)  
S. rugglesi Nicholson and Mickel  
S. jenningsi Malloch  
S. tuberosum (Lundstrom)  
Prosimulium mixtum Syme and Davies  
P. mysticum Peterson  
Ectemnia invenusta (Walker)